SILVICULTURAL MANAGEMENT OPTIONS

IN THE

MIXED DIPTEROCARP FORESTS OF SARAWAK

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Abstract

Data from three silvicultural research experiments in the mixed dipterocarp forest of Sarawak had been analysed to estimate gross basal area and gross sound stem volume increments of potential crop trees subject to various post-logging treatments, including the Malayan Uniform System, Liberation Thinning and Relic Removal. Growth functions had been estimated in a manner which enabled various hypotheses about treatments to be tested statistically.

The growth functions suggest that residual basal area of crop trees exerts a strong and positive influence on gross basal area increment - increment rising rapidly as crop tree basal area increases. However, there is a limit to this effect beyond which increment declines. Increment is negatively related to the basal area of non-crop trees. The volume functions behave similarly.

No statistical differences between treatment effects could be demonstrated. This implies that none of the deliberate treatments has been successful in promoting growth of the residual crop trees. Investment in post-logging treatment may therefore be misplaced and funds better spent on (1) treatment well after logging and (2) closer control of logging operations. Closer control of logging offers a cheap and effective way of ensuring crop tree basal area is maintained at the optimum level for stimulating growth and that logging damage is reduced. But it requires a higher level of planning of silvicultural and logging operations and implies the need for a prelogging sampling to guide prescriptions and post-logging sampling to enforce them.

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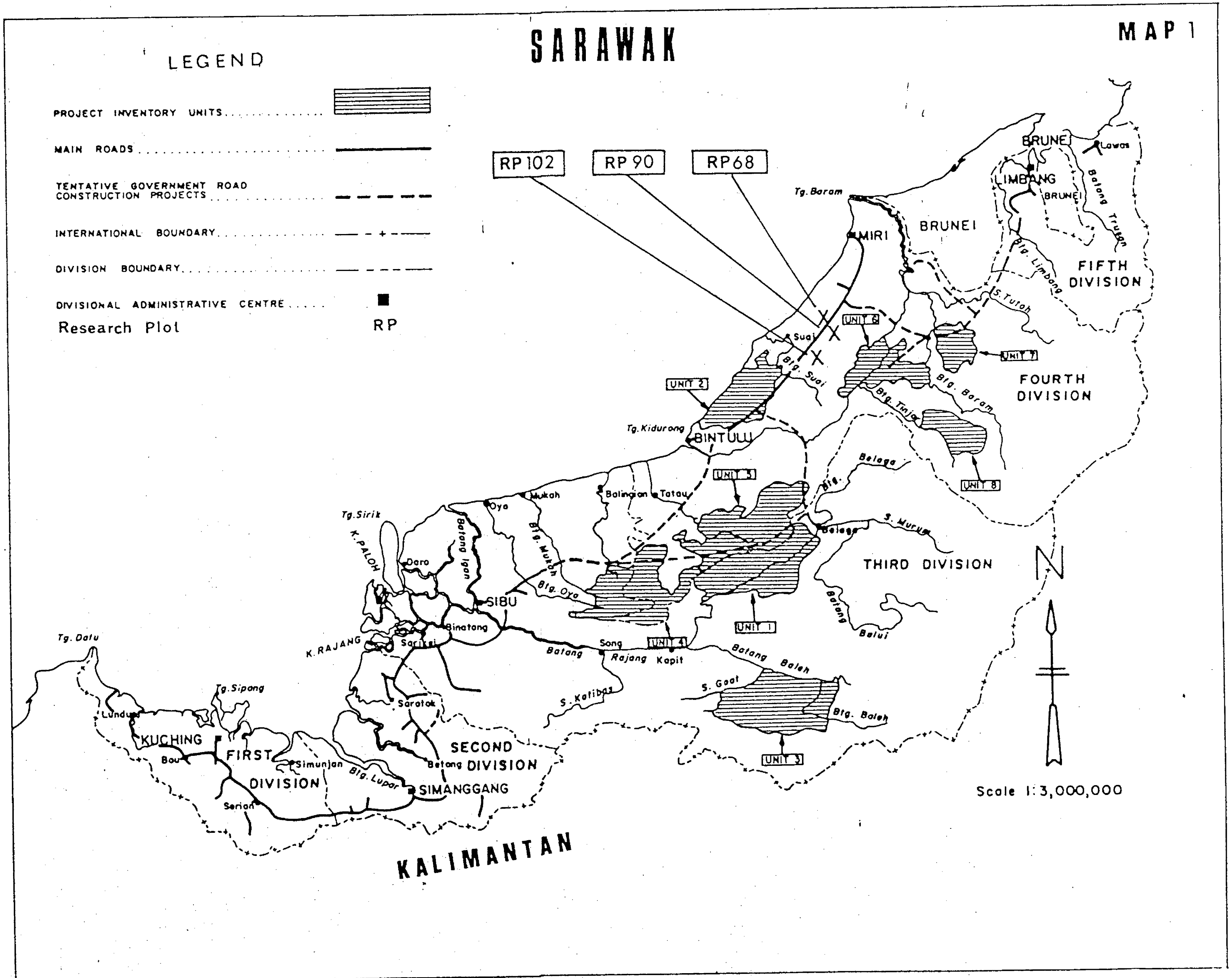
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CHAPTER 1

INTRODUCTION

Baur (1964) identified two basic types of silvicultural treatments in tropical rainforest; improvement treatment and regeneration. Improvement treatments are essentially a passing phase in the conversion of previously unmanaged stands to managed forests. Furthermore, improvement treatment forms an intrinsic part of treatment even where the emphasis is on regeneration establishment. Improvement treatment is concerned primarily with removing stems which, because of defect, poor form or species, are locally unmerchantable. This destruction of useless basal area allows the remaining desirable stems to grow at a faster rate than is otherwise possible. While it is usually carried out in conjunction with regeneration establishment, it can be applied to areas unlikely to be logged for a long period. This latter practice permits the potentially useful stems to attain a greater volume when logging is finally carried out and it leaves the forest in a better condition for subsequent regeneration treatments.

Silvicultural systems in use in tropical rainforest are based on these treatments but can be divided further into those producing an even-aged and those maintaining an uneven-aged, irregular type of forest. The type of treatment applicable to any particular rainforest area is determined partly by local economic and policy considerations and partly by the silvicultural characteristics of the main species present in the stand. Table 1 sets out the various economic and silvicultural features that may occur, and indicates the most appropriate treatment for each according to Baur (1964).

TABLE 1 : Indicators for rainforest treatment

Situation	Action
1. Forest not currently accessible for exploitation	(2)
1x. Forest available for exploitation now or in near future	(3)
2. No finance available for treatment	Reserve and protect
2x. Finance available for treatment	*Improvement treatment* (e.g. Congo:uniformisation par le haut)
3. Management for indirect benefits (e.g. watershed protection, recreation) paramount	*Selection system* (eg, Puerto Rico)
3x. Management for timber production paramount	(4)
4. Intermediate size classes plentiful; royalty rates make retention of these desirable	(5)
4x. Intermediate size classes relatively scarce	(6)
5. Severe opening of stand deleterious	*Selection system* (eg.NSW)
5x. Severe opening not deleterious	*Group selection* (eg.N.Qld)
6. Desirable regeneration adequate in virgin forest, or occurs readily with exploitation	(7)
6x. Regeneration not naturally adequate	(8)
7. Regeneration capable of responding to sudden and complete increase in light and exposure	*Clear-cutting* (e.g. 'uniform system' of Malaya, North Borneo)
7x. Regeneration needing partial shelter for some years	*Post-exploitation shelterwood* (e.g. T.S.S. of Trinidad)
8. Regeneration induced by canopy opening and cleaning	(9)
8x. Regeneration not readily induced naturally	*Artificial regeneration*, possibly combined with some other type of treatment (eg Reunion; N.Qld in part)
9. Regeneration, once induced, responding to complete light and exposure	*Pre-exploitation shelterwood* (eg. T.S.S. of Nigeria)
9x. Regeneration after inducement still requiring shelter for some years	*Extended shelterwood* (e.g. Andamans)

(Baur, 1964)

While Table 1 provides useful guidelines for the choice of silvicultural systems, there are some major issues which warrant further consideration.

1.1 Issues in Tropical Silviculture

1.1.1 Polycyclic versus monocyclic fellings in indigenous forest

The distinction between even-aged and uneven-aged systems of management is identified more in tropical silviculture between monocyclic and polycyclic fellings and there is considerable debate about their relative merits.

Traditionally, small trees of good species, remaining after exploitation, however few or poorly distributed, have been regarded as an important asset to be encouraged. Such a forest would then be managed under a modified selection system with periodic fellings at 20-25 year intervals to harvest mature trees and thinnings. Depending on the frequency and intensity of cutting, this may be regarded as an uneven-aged system. However, Dawkins (1958) saw little prospect of an acceptable level of productivity from tropical high forest for any such 'polycyclic' scheme of repeated cuttings. This view was based upon findings in Uganda to the effect that (i) large crowns which are essential to rapid growth cannot develop on trees subordinated in youth for a prolonged period by an older generation, and (ii) felling damage, which can average 0.02 ha per mature tree felled, occurs repeatedly in any polycyclic cutting plan, destroying or damaging the immature trees needed for future yields and ultimately reducing the net productivity to an intolerable degree.

The alternative form of monocyclic felling is based on the early and complete elimination of the canopy, whatever regeneration technique may be selected, leading to an even-aged system of management thereafter. The Regeneration Improvement Felling and the Malayan Uniform System practised in Malaya to be discussed later, are examples of monocyclic forms of felling. This form of management aims to simplify the composition of the forest to include only tree species of potential utility. Well over half the trees may be eliminated. The forest is expected to yield products sufficiently uniform to make for efficient harvesting and processing. This form of management usually entails long periods of time, perhaps 70-80 years, before the next commercial felling. In addition it eliminates species which are currently unacceptable, but are likely to have commercial value in the future. The reduction in species diversity also presents an objection in ecological terms.

1.1.2 Indigenous forests versus plantations

The choice between polycyclic and monocyclic management is further complicated by another alternative, the replacement of indigenous forests by plantations.

Traditionally, the replacement of forests with plantations, particularly of exotics, was looked upon as a risky digression from the natural course. However, proponents of the opposite viewpoint refer to the much higher yields obtained from plantations under favourable circumstances. They consider all other regeneration techniques to be likely to yield insufficient volume in the future and to be uneconomic. Thus in Brazil (Fishwick, 1975) interest in research in the indigenous species has been slight compared to plantation and exotic species. The slow growth and selectivity of local species with respect to sites has concentrated attention on the more spectacular results usually achieved with exotics.

In Papua New Guinea, White (1976) stated there was neither adequate age class distribution of advanced growth of suitable species nor a sufficient quantity of these species to allow natural regeneration to be used on its own for wood production purposes. In a study of natural regeneration reported by White in the Vanimo subprovince, the low stocking of commercial wood species and the attendant low timber volumes was attributed to the lack of opportunities for shade intolerant, efficient wood producing species to regenerate in quantity. Thus White (1976) argued for the replacement of indigenous forests by plantations.

Tang (1980) stated that the reason many tropical countries have turned away from natural forest management to plantations is largely a matter of economics. Profitability is, and will be, a major consideration in tropical forest management. Kio (1976) in examining the comparative costs of the artificial and natural systems of regenerating high forest in Nigeria and Uganda, suggested, however, that past economic models have favoured the plantation system due to the adoption of false premises. In a detailed analysis treated natural moist high forest was shown to be economically superior to plantation forestry. Kio maintained that the overwhelming superiority of plantations over natural regeneration was only valid where the forest to be converted is completely useless - such as degraded high forest with little or no advanced growth or open savanna.

Kio's analysis had been challenged by Moyini (1977) who said that 'just like those advocates of exclusive plantation forestry, he (Kio) carefully selected his variables and assumptions and proved his point'. Moyini maintained that to make a valid comparison between the merits and demerits of indigenous forests and plantations, one must carry out a complete social benefit-cost analysis that would include all costs incurred and all benefits derived. All possible alternatives such as different plantation species and management intensities, the cost of forest location from a regional point of view and opportunity cost of land should all be evaluated.

Nevertheless, because of the difficulties experienced with natural regeneration and the spectacular achievements of certain plantations of *Eucalyptus* spp., *Gmelina arborea, Tectona grandis* and *Pinus caribaea*, many foresters have proposed that natural forest should be replaced by predominantly monospecific plantations. This tendency gathered momentum after the World Forestry Congress in Buenos Aires in 1972 (Kio, 1980) and has been sustained by the readiness of international financial institutions to provide loans for plantation projects despite their reluctance to finance natural regeneration programmes. As well many tropical countries including those of southeast Asia (Tang, 1980) have accepted the inevitability of plantations.

Equally strong cases have been presented by many writers for the retention of natural regeneration techniques. Wadsworth (1965) maintained there is a place in tropical forestry for natural regeneration as well as artificial methods. What seems important, he suggested, is to strengthen the basis for comparison, and to appraise site potential and the stocking of young trees in existing forests before selecting the treatment. In any event, there is no lack of cleared areas where reforestation with plantations is needed and can be practised. It would be unwise, according to Tang (1980) to think of converting all or even the greater part of the natural forests to plantations of fast-growing tree species. The natural forests have very important traditional, social, conservational and scientific roles which cannot be adequately provided by plantation forests. Synnott and Kemp (1976) pointed out that future market demands for the final crop are uncertain at the time of regeneration of that crop; and this uncertainty places a premium on the flexibility in management to accommodate changing demands - a consideration which may in turn influence the choice of regeneration methods.

A major defect of most natural regeneration systems is the inability to predict precisely the future levels of wood production, either of particular species, or classes of timber, or indeed of merchantable wood. Nevertheless the natural variability of the forest may better accommodate changing markets. Synnott and Kemp concluded that whenever there is some doubt concerning the choice between natural regeneration and plantations, then the greater robustness and long term security of the natural system should be taken into account. The benefit of the doubt should be given in favour of maintaining the natural forest until the case for other forms of management is proved. Leslie (1977) also maintained that one of the best reasons for not completely abandoning management of the existing moist tropical forest lies in the distinct possibility that decisions based on this form of management being an uneconomic proposition could be wrong.

1.1.3 Summary

The choice of a silvicultural system is not a simple one between natural forest management versus plantations or between polycyclic or monocyclic fellings. In practice, management of forest lands may vary from a simple system in which silviculture is applied through logging at little or no cost at the extensive margin of forest location to the high investment plantation techniques at the intensive margin, with gradations in between. There are a great number of possible intensities of management (Worrell, 1956). An appropriate technique for a particular region is determined by many factors. These factors, as detailed by various authors (e.g. Ferguson and Reilly, 1975; Florence, 1978) include species composition, the adequacy of natural regeneration, conditions interfering with cultural work, forest location relative to markets, finance and labour, scale of operation, contractual commitments to supply constant annual volume to particular buyers, and requirements for environmental management. No one silvicultural system is likely to be generally applicable over a whole region.

An economic evaluation of different silvicultural management regimes for wood production must take into consideration circumstances that prevail in a particular forest area. However, an appreciation of the ecological requirements for the regeneration of desired tree species and a knowledge of future yields from various intensities of silvicultural treatments are essential prerequisites to any such economic evaluation. The aim of this study therefore is to predict yields for various silvicultural options in one of the most important forest types in Sarawak, the mixed dipterocarp forest.

1.2 Aims of the Study

The mixed dipterocarp forest of the State of Sarawak is recognised by the State authorities as a very valuable resource offering great potential for industrial development in the State.

In 1969, with the aid of the Food and Agriculture Organisation (FAO) of the United Nations (UN), the State Forest Department began an inventory of several large areas (Map 1) of this forest type identified as having the potential to sustain large scale industrial complexes. Data from this inventory have been processed and the results have been presented to the State Government in a series of working papers and technical reports which are summarised in FAO (1976). Based on these reports, the Forest Department has drawn up plans for the management of these large mixed dipterocarp forest areas. Long term licences have been issued for the logging and harvesting of these forests.

Many problems exist in managing this complex tropical forest ecosystem for the sustained production of wood for the timber industry; problems relating to regeneration and silvicultural management perhaps being foremost. The State Government therefore requested an extension of FAO assistance to develop guidelines for silviculture and management to supplement and reinforce the Department's research efforts in this field. A Silviculture Research Programme was established in 1974 as an independent section of the Kuala Lumpur-based FAO Project 'Forestry and Forest Industries Development in Malaysia', referenced MAL/72/009. The programme was subsequently transferred to another FAO Project 'Forestry Development in Sarawak' under the United Nations Development Programme (UNDP) referenced MAL/75/013 (1976-77) and MAL/76/008 (1977-81) based in Kuching.

Under the Research Programme, a series of silvicultural treatment experiments was established subsequent to a 'Guidelines Study' aimed at diagnosing the silvicultural condition of the forests. These experiments focus principally on a technique referred to as 'Liberation Thinning' and enables comparisons to be made with the Malayan Uniform System of treatment. Data from these experiments and others established by the Forest Department were edited and placed in computer files by a Consultant employed by the Project (FAO, 1979). These data form the basis of the present study.

In this study, preliminary analyses have been carried out on data from some of these experiments enabling tentative growth functions to be estimated for the mixed dipterocarp forest of Sarawak. The response of the regenerating forests to various silvicultural treatments has also been examined enabling recommendations on silvicultural options to be made for the silvicultural management of this forest type.

CHAPTER 2

SILVICULTURE IN MIXED DIPTEROCARP FOREST

The mixed dipterocarp forests of Southeast Asia extend in a broad arc from southern Thailand through Sumatra, west Malaysia, Borneo to the Republic of the Philippines. They form the main vegetation type on the western portion of the Indo-Malaya Rain Forest bloc (Whitmore 1975). Some seven species of the rain forest Dipterocarpaceae extend to New Guinea, but are generally of much less importance there than in the west, even though they do cover large areas (Paijmans, 1976). A review of the silvicultural systems in mixed dipterocarp forests in countries adjacent to Sarawak is therefore an appropriate starting point for this study.

2.1 Silvicultural characteristics of the Dipterocarpaceae

A detailed review of the silvics of the Dipterocarpaceae has been provided by Nicholson (1979). An important characteristic of the family is its irregular but abundant seeding (Wood, 1956; Burgess, 1972; Medway, 1972; Cockburn, 1975; Ng, 1977). Burgess (1972) demonstrated that dipterocarps seed heavily every 2-3 years with occasional intervals up to 5 years although some variation exists between species. Even in the best seed years only 40-50 per cent of mature trees in a given area are fertile and in some cases groups of trees flower together. Burgess also found that many dipterocarp species flower sporadically in any month of the year obscuring the existence of a regular maximum flowering in May.

Irregular seeding is coupled with a very short period of seed viability (Tang, 1971; Tamari, 1976; Sasaki, 1979) but a relatively long life of some of the seedlings. Data from Sabah reported by Whitmore (1975) show that 10 per cent of the 1961 recruitment was still alive after 9 years, a period quite long enough to bridge the seed year interval so there are usually adequate numbers on the ground. Under undisturbed conditions these seedlings hardly grow, height increments being as low as 1.2 cm a year (Nicholson, 1965). Numerous data (e.g. Browne, 1955; Vincent, 1961) show a rapid and marked response to increased light resulting from felling or natural mortality. Fox (1972) quoted increments in heights of 3 m or more for seedlings in the two years after felling and Liew and Wong (1973) cited similar data. Growth data from yield plots indicated very rapid seedling and sapling increments e.g. 1.9 cm a year in diameter growth in 4 year-old regeneration (Fox, 1972). Vincent (1961) also showed the necessity of heavy girdling in the second storey and some opening in the top overhead canopy if further development of regeneration on the ground was to be achieved.

Although young seedlings show a strong positive response to light, they do not always appreciate completely open conditions. This is shown by experiment (Nicholson, 1960) and by observation (Nicholson, 1970; Fox, 1972; Hutchinson, 1977). Some groups are slower growing and less able to withstand exposure (Whitmore, 1975), but even the more intolerant species grow best during their establishment phase in semi-shaded conditions. Nonetheless, maximum survival and growth occur in full light provided moisture and temperature are not limiting and this indicates that the weather conditions at the time of logging are critical. Germination is also good in humid open situations (Nicholson, 1979). In general, however, the retention of scattered shade provides good growth conditions for seedlings by preventing excessive insolation and desiccation in adverse weather.

Once establishment and initial growth is assured, the sooner full overhead light is provided, the better will be the response in growth. Nicholson (1979) reported that the best growth of dipterocarps occurs where there is a rapid return to closed canopy with complete soil cover, but with the dipterocarp component in a dominant position in the canopy. This is likely to occur within 18 months in logged forest because secondary species quickly provide soil cover.

The presence of dipterocarp seedlings on the forest floor prior to disturbance is an important prerequisite for successful regeneration (Nicholson, 1958; Wyatt-Smith, 1963). Liew and Wong (1973) reported that recruitment after disturbance had a higher rate of mortality and slower growth rate. It is extremely important that existing seedlings be protected in any logging operation. Tractor paths and cableways should be kept to a minimum as dipterocarp regeneration is readily destroyed by such disturbance. Recolonization of disturbed areas is slow due to poor soil conditions and lack of a regular seed fall (Nicholson, 1979). Vine growth becomes so excessive that new plants just cannot compete.

Although seedlings respond very quickly to treatment or logging, less information is available about the response of advance growth in the residual stand. This response is important for any consideration of polycyclic logging (Florence, 1976; Nicholson, 1979). Nicholson (1979) quoted figures from Sabah (Anon, 1964) which indicate that the average diameter increment of 127 trees between 10 and 58 cm diameter was 1.0 cm per annum for three years after logging, compared to that of 0.4 cm per annum for 127 trees of the same diameter range for 3 years prior to logging, the increase occurring in all tree sizes. Nicholson suggested that the effect could be common to the other areas of South-east Asia, although differing in order of magnitude depending on species composition and site factors. This ability of advance growth to respond to release enhances their potential as a basis for the future crop.

2.2 Silvicultural practices in mixed dipterocarp forests

The mixed dipterocarp forest is the main vegetation type in insular South-east Asia and has been heavily exploited since 1960. Removals, estimated to be about 17 million m^3 in 1966, increased two and threefold in 1970 and 1975 respectively (Nicholson, 1979).

The intense exploitation of the mixed dipterocarp forest has generally not been accompanied by appropriate logging and management practices to ensure sustained productivity. This is of deep concern not only to foresters and ecologists but also to industrialists, who fear that the resources will be exhausted in the next one or two decades with harmful consequences to the environment and economy of the region (Huguet, 1979).

2.2.1 Peninsular Malaysia

The development of silvicultural systems in the lowland dipterocarp forests of Peninsular Malaysia has been reviewed by Florence (1976). The earliest silvicultural technique used in lowland forest reserves of P. Malaysia was a form of shelterwood system referred to as 'Regeneration Improvement Fellings' (RIF). In the first of several operations the less desirable species were removed commercially or were poisoned; and where necessary an understorey clearing was carried out. The fellings were disposed of as firewood, charcoal or mining timbers. These operations were intended to provide suitable environmental conditions for the development of regeneration of the remaining desirable species. Some six years later the final felling of the desirable species took place, leaving the evenaged regrowth to develop.

With few exceptions, the RIF proved to be a highly successful technique in rain forest management. Despite this it was replaced in the early 1950s by the Malayan Uniform System (MUS). The system is fully defined by Wyatt-Smith (1963). Briefly the system is the removal in one operation of all the economic crop from areas that have been shown by sampling to carry an adequate stocking of regeneration. This logging is followed by a poison-girdling of all the remaining uneconomic canopy and all smaller trees down to about 5 to 15 cm diameter, excepting commercial species of good form. This very drastic treatment definitely favoured the quicker growing meranti timbers (*Shorea* spp.) at the expense of the heavier hardwoods, but it was hoped that enough of these would be able to survive and grow. This was usually the case. Advance growth was accepted but not relied upon as a component of the next cut, nor were special measures taken to preserve it from damage. It was regarded as a bonus where present. The system relied on seedlings present at the time of logging to form the bulk of the following crop.

Logging and marketing factors, rather than ecological factors, forced the change from RIF to MUS. Under the impetus of mechanisation in extraction and milling practice after World War 11 and the greater demand for Malaysian timber, both local and overseas, there was an increasing need for a single, heavy logging of the forest. Fortunately such a move seemed to be ecologically justified. Under the RIF, the initial felling and clearing was designed to induce regeneration but wide experience had shown this to be unnecessary. Seedling regeneration of desirable species was widely present on the floor of unexploited lowland dipterocarp forests.

The MUS was further modified when land pressures for agricultural development strengthened. Much of the forest which had been logged and treated using RIF and MUS techniques occupied high quality lowland sites accessible to major centres of population. This has been cleared or will be cleared for agriculture within the next one or two decades (Burgess, 1973). Thus future wood requirements will have to be met from hill forests, above 300 m contour and generally with slopes greater than 20 degrees, this land being entirely unsuitable for agriculture and therefore designated for sustained forest management, even though barely suitable for it. The MUS was applied in these hill areas but was generally found to be inappropriate. New silvicultural techniques had to be developed.

Ecologically, the hill forest is characterised by the lack of seedlings in the virgin stand and the comparatively slow growth and shade-demanding nature of young regeneration which originated under a dense shade. The stocking of commercial trees is irregular, leading to wide differences in the size of openings created by felling. Heavy seedling mortality occurs during exploitation, especially on steep slopes, because of the difficulty in controlling logging operations in the steep terrain. The high cost of hill logging stemming from the high cost of road building and road maintenance necessitates a high volume in the first cut to offset the cost. Burgess (1970) carried out extensive studies in the hill forests of Peninsular Malaysia and concluded that no one silvicultural procedure can be applied to all forest types found in the hills of the Malay Peninsula. The Forestry Department of Peninsular Malaysia is therefore faced with developing new silvicultural techniques under complex environmental conditions, and with the dilemma of ensuring that these techniques guarantee a continuing flow of timber for highly capitalised, sophisticated multi-product industries. In order to do this, some form of selection logging had to be developed as a means of 'drawing out' existing log supply to industry. The Forestry Department of Peninsular Malaysia recently adopted a 'bicyclic' cutting system for the management of large concessions in the hill forests.

Basically, the system or 'Selective Management System' as it is called is the 'application of cutting regimes (minimum diameter cutting limits) over a specified area of forest that will yield an economically viable amount of timber while retaining adequate advance regeneration for a future economical cutting cycle in the shortest possible time' (Griffin and Caprata, 1977). The system is based on a pre-felling inventory which includes characteristics like climate, soil, ecological balances and human demands (economic, socio-political and technological considerations). The forest manager then finds a suitable cutting regime to achieve, as close as possible, the objectives of the system. The system is considered (Zulmukhshar Shaari, 1979) to be flexible enough to cater for all variations found in the forests as well as being economically viable in terms of harvesting. The system recognises the need to make more efficient use of existing growing stock by ensuring that the cut avoids 'creaming' all the faster growing dipterocarps and that a fair proportion of the cut comes from the non-dipterocarp component of the forest.

If selection logging of rainforests is to provide a sustained yield of timber products three assumptions must be made.

1. The stand contains an adequate stocking of intermediate size trees of economic species.
2. Logging damage to these trees will be minimal and will not affect the adequacy of the residual stocking.

3. Intermediate size trees are able to develop full size crowns under shade or are able to expand an initially stunted crown (Florence, 1976).

Thus adequate prelogging inventory must be carried out and a higher level of logging supervision is required. More information on the response of the intermediate size trees must also be obtained.

2.2.2 Sabah

According to Nicholson (1979) real control of forest exploitation in Sabah up to 1952 was in the hands of the British Borneo Timber Company which was formed in 1919 with a monopoly on all timber exports. After 1952 there was a great increase in logging with the entrance into the industry of three other large overseas firms, and later by a further eight local companies. By the late fifties almost all logging of any significance was mechanised with most firms using crawler tractors and with two firms also using high-lead systems in rather more rugged country. A full account of one logging operation is given by Nicholson (1958). A similar paper by Fox (1968) shows that the industry had continued to expand with heavier and more powerful machinery being used. This expansion has continued into the seventies and huge areas are being felled. As in Peninsular Malaysia there is a strong demand to develop much of the suitable forest land for agriculture and much of the huge volume (14 million m^3 off 162,000 ha) (Nicholson, 1979) is coming off such land. As well, there is a strong political pressure to convert forest capital to social capital.

In Sabah, with similar forest to Peninsular Malaysia and very often with senior personnel with Malayan experience, it was natural that the initial system of management would be the MUS. The first areas were treated in 1955 and for a number of years there was a rapid expansion with treatment operations being located around all major logging camps. By 1963 13,500 ha were being treated annually. Two accounts by Nicholson (1958a and 1965) cover the treatments and results obtained. Following experiments in Sabah, some divergence from the original system in Peninsular Malaysia occurred and led to the preparation of the Sabah Forest Record No. 8 (Anon. 1972), but in the main silvicultural treatments in the two regions were very similar. The divergence centred mainly on the importance of advance growth for intermediate yields and the reduction of logging damage to advance growth.

With the huge expansion of the annual cut in the late sixties and early seventies it was impossible for silvicultural treatments to keep pace and a large backlog of untreated forest accumulated. In early 1977 all treatment was stopped, after the appearance of a paper by Chai and Udarbe (1977) which cast doubt on the usefulness of treatment. Chai and Udarbe noted that owing to the high intensity of logging, silvicultural treatment was effectively restricted to one-third of the cutover area, the other two-thirds having been released by logging.

Several concurrent developments encouraged changes in the silvicultural system. Firstly, the increased intensity of logging practices led to more damage to soils from heavy equipment. Secondly, the steadily increasing average volume removals affected soils and regeneration. Lastly, very vigorous invasion of 'belukar' have been observed after heavy logging and treatment. As a result poisoning or any other silvicultural treatment immediately after heavy logging in Sabah is no longer considered appropriate.

2.2.3 The Philippines

Mechanisation of logging operations occurred earlier in the Philippines than elsewhere in South-east Asia. Because of the steepness of much of the country, the high volumes and the influence of lumbermen from the west coast of North America, high-lead logging systems are common.

A Selective Logging System is currently employed to reduce damage experienced in earlier logging systems. These appear to have been controlled by a diameter limit of the order of only 50 cm, resulting in 60% denudation on some high-lead settings (Serevo, 1949) and heavy damage to residuals (Wyatt-Smith, 1954). The system is described in the Handbook on Selective Logging and is further discussed by Glori (1979) and Nicholson (1979). Essentially, a 5% sampling of the growing stock is carried before logging to guide tree-marking for retention of undamaged stems. A residual inventory provides data for assessing fines and estimating future yields.

Tree-marking following the 5% sampling identifies a certain percentage of healthy young commercial trees which must remain undamaged through the logging operation. Nicholson (1979) indicates marking for retention of trees in the 15-65 cm diameter range and 40% of those in the 65-75 cm range, while Glori (1979) gives the same percentage figures but in the 20-60 cm diameter range and the 70 cm and above class. Actual logging seems to take out 25% of the 55-65 cm diameter trees, 55% of the 65-75 cm trees and all trees over 75 cm (Nicholson, 1979). The residual inventory after logging is a 100% count to determine the number and condition of the residual trees.

According to Nicholson (1979) no treatment has been done on a routine basis because logging is seen as the implementation of the silvicultural practice where removals are planned to leave a residual stand and to assist its growth. Glori (1979), however, refers to a Timber Stand Improvement which, as recommended in the Handbook of Selective Logging, should not be carried out earlier than four years after logging. Reyes (1978) has indicated that the residual stand does respond to silvicultural treatment.

In general it seems that the system is complicated and provides room for abuse, especially in the marking for retention, because it allows marking to be confined to the lower end of the wide diameter range. Nicholson (1970) after studying the marking rules suggested that a number rather than a percentage of the growing stock be set as the minimum marking goal and that the felling limit be 70 cm and above. However, his suggestions were apparently not taken up. Glori (1979) admits that 'while significant studies have been made in the field of forest utilisation, the production aspect has still to come up with a system most appropriate for the management of forest lands'.

Nicholson (1979) notes that large industrial complexes which produce sawn wood, plywood, chipboard, hardboard, pulp and paper are being developed to meet a large local demand for wood and wood products. The allowable cut of forests supplying these plants has been set at ambitiously high levels and there are indications that other sources of logs may be necessary to ensure supply at the designated rate.

2.2.4 Indonesia

The last decade has seen a boom in logging of the dipterocarp forests in Indonesia, rendering timber, since 1969, the second largest earner of foreign exchange in the country.

There is some uncertainty concerning silvicultural management in Indonesia. Although Soerianegara (1970) concluded that certain silvicultural systems should be applied in conjunction with cutting regulations to prevent degradation of the natural forests due to large scale logging, he did not specify any particular system but suggested that one of the following systems might be applied.

1. The Indonesia Modified Selection System.
2. The Philippines Selective Logging System.
3. The modified Malayan Uniform System.

Nicholson (1979) quoted Boerboom and Wiersum (1977) as saying that the silvicultural system to be applied can be chosen by the logging company.

The Indonesian Modified System consists of:

1. Forest and regeneration inventory before logging.
2. Tree marking for felling and retention, depending upon the diameter limit and the rotation and cutting cycle as follows:

Diameter limit (cm)	Cutting cycle (year)	No. selected trees to be left	Diameter selected trees (cm)
50	35	25	35
40	45	25	35
30	55	40	20

3. Residual stand inventory, cleaning of weeds and climber cutting, restocking of open areas and poorly stocked parts after logging.
4. Tending operations five years after logging as follows:

(a) clearing weeds to free reproduction from weeds and climbers,

(b) restocking of poorly stocked parts,

(c) thinning if necessary.

The Indonesian Modified Selection System is very similar to the Philippines Selective Logging System, differing to the extent that some of the limiting sizes are different and an *ad hoc* table of numbers of trees per ha is used instead of a percentage (Nicholson, 1979). The Indonesian Modified Selection System is basically sound but rarely implemented because of a lack of trained staff, making it impossible to enforce the regulations.

Some forest concessionaires in Indonesia are showing great concern about the perpetration of the dipterocarp forests. The Weyerhaeuser group for instance (Carmichael and Hughes, 1976, 1977) has set up a tropical forestry research unit in East Kalimantan concerned with the establishment of growth plots and dynamic studies in the dipterocarp forests to determine cutting cycles, allowable cuts and to forecast long term yield.

2.2.5 Conclusions

Almost all the regions under review share the common characteristic of a very high rate of exploitation of the mixed dipterocarp forests. Forestry authorities are generally concerned about the high degree of damage caused to the residual stand by logging and the deleterious effects to the environment. Certainly most forestry authorities would like to see the rate of exploitation reduced. Generally, environmental movements opposing logging are not strong. Concern about damage to the forests and the environment are not usually shared by governing authorities. Although forestry authorities would like to see more control being exercised and closer supervision placed on logging operations, this is generally not possible because of inadequate resources, both in terms of trained manpower and finance. This is ironical because forestry is often one of the largest revenue earners in the countries concerned.

There is a general tendency in the region to adopt selective logging systems aimed at making better use of the existing growing stock and at the same time conserving a large portion of it for later cuttings. But these have met with limited success because of the inability to ensure that the residual stand survives undamaged following logging. None of the systems in use seem to be able to sustain the present level of cut.

Although most countries in the region still persist with natural regeneration practices, there is a growing acceptance of the need for, and indeed the inevitability of, artificial regeneration or conversion planting to increase the future yield of timber from the region. Where logged-over forests are devastated by shifting cultivation, as in many areas of Southeast Asia, the need is even more pressing.

CHAPTER 3

FORESTRY IN SARAWAK

Sarawak is located on the northwest coast of Borneo and is one of the thirteen States in the Federation of Malaysia. The State capital, Kuching, is about 1000 km east of Kuala Lumpur, the nation's capital. Forests are stated to occupy over 9.4 million ha or 76% of the land area (Forest Department, 1979). Much of the hinterland is steep and receives a high rainfall, over 3500 mm annually. There are, however, extensive areas of flat swamp land and up to the late 1970s swamp forests were the most productive forests, ramin (*Gonystylus bancanus*) being the most important species.

The forests - evergreen tropical rainforest - are natural, very largely of hardwoods, and are generally dominated by dipterocarps. High yields have been obtained from the first cutting cycle which is still in progress. There are virtually no plantations. Production is almost entirely from State-owned forests.

3.1 Economy

In 1979 the population of the State was estimated to be 1.23 million. The annual rate of population increase from 1970-1977 was 2.5-2.6% (Department of Statistics, 1979). About 80% of the population is rural.

In 1975 the Gross Domestic Product (GDP) was M$2,034 million with forestry and logging comprising M$69 million or 3% of this total (Department of Statistics, 1979). Between 1971 and 1979, preliminary figures from the Department of Statistics showed a real growth rate on GDP of 7.7% per annum. Real growth in the forestry and logging industry was

10.4% per annum and exceeded this rate; it has been particularly rapid in the 1975-79 period - 21% per annum in real terms. Per capita income was M$1230 in 1979 (State Planning Unit, 1980).

The value of exports has exceeded that of imports in external trade since at least 1968. Up to 1972 these surpluses had been increased by re-export of oil products from Brunei. Sarawak's own oil production has increased since the early 1970s. Nevertheless, in 1978 forest products exports earned over M$490 million (Forest Department, 1979) and comprised about 25% of the total value of exports - second in importance after oil.

3.2 Land and Land Use

Of a total of 123,000 km^2 in Sarawak about 11,000 or 8% are considered suitable for agriculture, and 17,000 or 14% are marginal for agriculture, leaving 95,000 or 78% to be kept for forest. With a population of about 1.23 million there are currently 10.0 ha of land per caput.

Statistics as to land uses, almost unchanged during the past decade are currently under revision, and are expected to show a significant reduction in forest area. Those available in 1978 indicate that less than 1% of the land surface is urban or in other non-agricultural uses, less than 4% is in permanent agriculture, and more than 23% is in shifting agriculture. This indicates that as much as 72% of the land or 89,000 km^2 was forest covered.

Permanent agriculture now occupies about 352,000 ha or about one third of the land considered suitable for agriculture. Shifting agriculture is the most active agricultural enterprise. Between 65,000 and

120,000 ha are currently slashed and burned annually, destroying some 34,000 ha of virgin land. Some 100,000 ha of hill padi, a dietary staple crop, are produced in this way.

3.3 Forest Economics in Sarawak

The economic guidelines given in the published Forest Policy laid down in 1954 (reproduced in Forest Department, 1976) include:

' ... the supply in perpetuity and at moderate prices of all forms of forest produce that can be economically produced and that are required by the local population'.

'... to manage the productive forests .... to .... obtain the highest possible revenue compatible with the primary objects (of the policy)'.

'... to foster, as far as may be compatible with the prior claims of local demand, a profitable export trade in forest produce'.

With an abundance of forest, a small population, and a prosperous and expanding economy, forest policy makers appear to be in an unusually favourable position. There are real problems, however, including shifting cultivation, modernisation of industry and the reliability of sustained yield.

A fuller discussion of forest economics in Sarawak is available in FAO (1980).

3.4 The Forest Resource

The following details concerning the forest resource of Sarawak were extracted from FAO (1980) in its report concerning the Project for Forestry Development in Sarawak MAL/76/008. A major revision of forest area is currently being undertaken by the Forest Department based largely on aerial photographs taken since the early 1970s. The published areas of forest will probably be revised downwards as a result, so the areas and standing volumes given are subject to amendment.

3.4.1 Forest area by forest types

There are three main types in the 9.4 million ha of forest land in Sarawak; the mangrove, peatswamp and hill forests.

The mangrove forests are found in the estuaries of the main rivers. They contain more than 40 tree species and areas of Nipah palms. Historically, they were the basis of a cutch (tannin industry), but now supply firewood, charcoal, poles and woodchips.

The peatswamp forests have three sub-divisions: mixed swamp, alan and padang forests. The mixed swamp forest has five main commercial species - ramin, jongkong (*Dactylocladus stenostachys*), swamp jelutong (*Dyera lowii*), sepetir (*Copaifera palustris*), swamp kapur (*Dryobalanops rappa*); and a commercial 'group' - swamp merantis (*Shorea* spp.). Ramin has been the main species exported in the processed form from 1946 till the late 1970s. Alan forest is dominated by tall, often hollow trees of alan (*Shorea albida*) which can form virtually pure stands. Padang forests are on poorer sites, with generally stunted growth. They have limited production potential. Development in mixed swamp forest and alan forest has probably reached its peak, but these forests still dominate the sawmill, moulding and dowel industries.

The hill forests are made up of the mixed dipterocarp forests, the kerangas forests and the montane forests. The mixed dipterocarp forests range in elevation from sea level to about 750 m. They contain more than 2000 tree species but dipterocarps comprise about two-thirds of the commercial timber volume. A fuller description of this forest type, the subject of this essay is given in Section 3.6. The kerangas forests are generally non-commercial, containing small trees of poor form and small size on poor, white sandy soils. The main species are *Casuarina* spp., *Agathis alba, Dacrydium* spp., *Tristania* spp. and infrequently *Shorea albida*. Above 750 m elevation the dipterocarps are replaced by montane forests which comprise tree species not likely to be utilised. Nevertheless the montane forests have important protective functions.

The relative areas of the various forest types are presented in Table 3.1.

TABLE 3.1 FOREST AREAS BY TYPES

Forest type	Area (mill. ha)		Forest area (%)		Land area (%)
Mangrove		0.17		1.8	1.4
Peatswamp					
Mixed	1.17		12.4		
Alan	0.19		2.1		
Padang	0.11	1.47	1.1	15.6	12.0
Hill					
Mixed dipterocarp	5.86		62.1		
Kerangas	0.37		3.9		
Montane	1.56	7.79	16.6	82.6	63.2
TOTAL		9.43		100.0	76.6

3.4.2 Forest legal divisions

Control of forests in Sarawak is vested in the Forest Department. There are two main legal forms of tenure - 'Permanent Forest' and

'Stateland Forest'.

Permanent Forest has three sub-divisions: Forest Reserve, Protected Forest and Communal Forest. Areas of forests by these divisions are given in Table 3.2. The sub-divisions are described (Forest Department, 1977) as follows:

> 'A Forest Reserve is set aside for productive forestry destined to be the principal permanent source of the country's supplies of timber and other forest produce. A Protected Forest is constituted both for productive forestry as well as for the general protection of soils and waters. The Law admits certain rights to the people for the taking of forest produce for domestic use and for hunting and fishing (which are not permitted in a Forest Reserve), while a Communal Forest is constituted for local communities to serve their domestic needs for timber, fuel and other produce'.

In Stateland Forest, licences for forest utilisation are issued by the Forest Department, but it does not control the land. Stateland Forests are usually destined for agricultural development after clear-felling.

TABLE 3.2 FOREST AREAS BY TYPE AND LEGAL STATUS ('000 ha)

Legal Status	Mangrove	Swamp	Hill	Total
A. Permanent Forest				
Forest Reserves	28	338	382	944
Protected Forest	13	342	2041	2396
Communal Forest	0	4	27	31
Subtotal	41	684	2450	3175
B. Stateland Forest	133	790	5338	6261
Total	174	1474	7788	9436

3.5 Forest Utilisation

Forest utilisation is regulated by the Government, through licences issued by the Forest Department. By the end of 1979, 4.45 million ha were under licence; by tenure about 2 million ha was of Permanent Forest and about 2.5 million ha was of Stateland (Forest Department, 1979). Licences over Permanent Forest are issued under Working Plans, those over Stateland are issued under Felling Plans.

Practically all the Mangrove and Swamp Forest has been licensed and about a third of the Hill Forest. The average size of licenses:

	Swamp	Hill
Permanent Forest	20,000 ha	61,000 ha
Stateland	6,000 ha	20,000 ha

In addition there are over 160 current licences covering belian (a durable ironwood species) extraction; and licences for minor forest operations.

The Permanent Forest licensed areas are big enough to ensure a sustained yield for relatively large scale forest industries. The Swamp Forest licensed areas are generally much smaller than those in Hill Forest, but are geared to industries which are already well established.

3.5.1 Production

Current timber harvesting (1979) yields about 7,500,000 m^3. More than 90% of the product is disposed of in log form. Other products include 340,000 m^3 of sawn timber, 19,000,000 m^2 of veneer, 5,900,000 m^2 of plywood, 86,000 m^3 of mouldings, 21,000 m^3 of laminated board, and

120,000 tonnes of woodchips.

The log production in 1979 of 7,500,000 m^3 represents a 25.7% increase over the 1978 figures. Log production in the hill forest rose by 35.7% to 4,250,000 m^3 while production from the swamp forests rose by 14.8% to 3,250,000 m^3. The Forest Department (1979) anticipates that production from the swamp forests will stabilize at 3,250,000 m^3, while production from the hill forests will continue to increase as newly licensed areas begin operations.

About one-third of the value of the forest products is contributed by labour. The production of forest products employs 30,000 to 40,000 workers, nearly 10% of the total labour force in Sarawak and about 30% of all employment, excluding farming. 60% of the forest employment is direct and 40% indirect. Of the workers directly employed, 65% are engaged in logging and 35% in processing. Employment in the timber industry has increased at a mean annual rate of 5.2% during the past 11 years.

3.5.2 Consumption

Local consumption of timber products is about 600,000 m^3 per year including 150,000 m^3 of sawn timber, 15,000 m^3 of plywood and 8,700 tonnes of paper and paperboards.

3.5.3 Trade

About 90% of the log production and 60% of sawn timber production is exported. Export value rose from 2,700,000 m^3 in 1969 to 6,000,000 m^3 in 1979, an average annual increase of 8.3%. Log exports go to Japan and the Asian mainland, but most of the exported sawn timber goes to Europe.

Forest products imports to Sarawak in 1979 totalled 270,000 m^3 roundwood equivalent volume, including logs for processing and re-export, sawn timber and paper and paperboard.

3.6 The Mixed Dipterocarp Forests of Sarawak

The mixed dipterocarp forest forms the main forest type in Sarawak, covering approximately 62% of the forested area or 5,860,000 ha. It occupies most of the area from the inland limit of the peat swamps to the lower limit of the montane forests at the elevation of 750 m asl. The area is, for the most part, hilly, deeply dissected or mountainous.

3.6.1 Potential commercial forest area

Of the 5,860,000 ha in the hill region, after elimination of the montane area and kerangas forest, another 760,000 ha are likely to be taken out as natural reserves (National Parks and Wildlife Sanctuaries) for the conservation of plant and animal species and native ecosystems. This leaves some 5,100,000 ha; of this, 810,000 ha has already been exploited. The balance will be further reduced by shifting agriculture.

With regard to shifting cultivation two prospects are foreseen (FAO, 1980a). The first is that shifting cultivation will continue to expand into the forests at rate growing with rural population and at the same time using periodically all lands currently cultivated. The second prospect is that in 30 years, through the efforts of government extension and technical assistance programmes, shifting cultivation will be concentrated on just the lands suitable or marginal for agriculture. The first prospect sees shifting cultivation which remains unrestrained to fell an area of some 500,000 ha of the mixed dipterocarp forest within the next 30 years in a manner that precludes future harvest of the timber. With an area of some 800,000 ha already exploited, an area of less than 4,000,000 ha is left for the export market.

3.6.2 Structure and composition

In its primary state, the mixed dipterocarp forest generally consists of:

(i) emergent trees of some 60 m in height;

(ii) a dominant and codominant stratum having a height of about 45 m;

(iii) an intermediate layer of trees with canopies of between 23 to 30 m; and

(iv) suppressed vegetation.

In some instances, where emergent trees are rare, the forest becomes a three strata stand. Ground vegetation is of moderate density. An inventory of 1,200,000 ha of mixed dipterocarp forest in eight large units concluded that slopes in excess of 35° and elevations in excess of 750 m are low in commercial volume and subject to erosion.

The forest is dominated by the family Dipterocarpaceae which accounts for between 65 to 80% of the net industrial stemwood volume of trees having diameters in excess of 30 cm. A significant feature of the forest type is that over wide areas, average stand volumes and volumes in terms of the main commercial timber groups are remarkably uniform. Gross volumes of stemwood in trees of commercial species of more than 45 cm dbh and 3.7 m straight bole length average 131 m^3/ha, ranging from 94 for stands of medium density to 145 in those of high density.

The inventory recorded 606 species (of which 179 were dipterocarps) from 210 genera of 61 families. Non-dipterocarps, which account for roughly 30% of net volume, consists of 427 species from 201 genera and 60 families occurring with sufficient frequency to be considered as important commercial species under existing circumstances.

A large number of dipterocarps enter the timber market under broad group names. The following list summarizes the species composition of the main timber groups encountered during the inventory:

Timber Group (vernacular name)	No. of Species Entering Group
Mersawa	5 spp. of *Anisoptera*
Keruing	28 spp. of *Dipterocarpus*
Kapur	5 spp. of *Dryobalanops*
Chengal	4 spp. of *Hopea*
Luis (Merawan)	14 spp. of *Hopea*
White Seraya	4 spp. of *Parashorea*
White Meranti	5 spp. of *Shorea*
Yellow Meranti	17 spp. of *Shorea*
Dark Red Meranti	15 spp. of *Shorea*
Red Meranti	35 spp. of *Shorea*
Selangan Batu	26 spp. of *Shorea*
Resak	1 sp. of *Upuna*
	16 spp. of *Vatica*
	2 spp. of *Cotylelobium*

A full discussion of the results of the inventory is given in FAO (1974).

3.6.3 Site-forest relationships

Two major studies have been carried out on site-forest relationships of this forest type in Sarawak so far. One has been reported by

Ashton (1973) and the other by Baillie (1978). The latter study was an investigation of some of the relationships between site conditions and the composition, structure and hollow decay in stands. This was a sequel to Ashton's earlier work in these forests in Sarawak and Brunei.

In general, the results of Baillie's study indicate strong site-forest interaction, and suggest that the floristic diversity in these forests is partly due to adaptation to multiple edaphic niches. Data deficiencies and the inconsistencies in the results preclude strong recommendations for the refinement of silvicultural, forest inventory or soil survey procedures. However, they do indicate that site preferences will have to be considered if artificial plantations of dipterocarps are ever attempted.

3.6.4 Timber production and industrial development

Though small scale logging in the hill forests occurred before World War 11, the timber industry relied mainly on the extensive areas of peat swamp forests. By the mid-1960s the effects of depletion of these forests became evident and sustained logging in the hill forests was begun. The first hill reserve however, was not licensed for logging till 1969. Till that time, the bulk of production had come off stateland forest areas over which the Department of Forestry had no direct legal control.

The commercial harvesting of the mixed dipterocarp forest of Sarawak has so far been geared towards the export of logs. However the Sarawak Government is implementing a policy which will encourage the development of integrated forest industries based on forest areas identified during the FAO-assisted inventory (Section 1.2) as having the potential for such developments. Forest concessions granted in the hill forests on the FAO inventory areas come under the control of the Sarawak Timber Industry Development Corporation (STIDC) which was established under Ordinance 3 of 1973 and given wide powers for controlling and monitoring all sections of the timber industry (Thorpe, 1978).

The objectives of the large scale concessions in the FAO assessment areas are:

1. to export the produce;
2. to build up sawmilling and the veneer mills; and then further manufacturing units;
3. to limit the log exports to 30% of the logs cut;
4. to allocate licences for 25 years (generally, but some are for 10 years);
5. to manage the areas for sustained yield on a 25-year cutting cycle. Control would be by area.

The target figure, once the sawmills and veneer mills are in production, is:

Annual area felled	41,820 ha
Total log production	2,712,000 m^3
Volume per ha	64.8 m^3
Sawmills input	1,038,700 m^3
Veneer/ply input	575,100 m^3

(FAO, 1980).

These targets are not yet met. At present, some 30,000 ha of the mixed dipterocarp forest reserves are being harvested annually.

3.6.5 Current management in mixed dipterocarp forest

As noted earlier, old-growth stands of mixed dipterocarp forest are being licensed for logging for varying periods, depending upon the legal status of the land. In areas of stateland forest being alienated for agricultural and other development, short term felling plans are written for the orderly removal of timber to ensure as complete a utilisation as possible.

In permanent areas, a system of management plans is drawn up in accordance with the policy 'to manage the productive forests of the State for the supply in perpetuity of forest produce in accordance with the principle of sustained yield'.

Each management plan is applicable to a specific industrial unit formed by an aggregation of a few permanent forest areas to make each a sizeable unit of some 61,000 ha (Section 3.5).

The following goals are stated in the management plan (Forest Department, 1979):

(a) the optimal utilisation of the forest resource;

(b) the regulation of the harvest on a sustained yield basis;

(c) the regeneration of the forest and the improvement of the stocking of useful species by proper silvicultural techniques.

Lacking the experience in hill forest logging, Sarawak has tended to model its management system along the line of that in the hill forest of Peninsular Malaysia. A cutting cycle of 25 years is adopted for the management plan as a 'bycyclic cutting system' (Section 2.2.1). Harvesting operations are centred on the selective removal of mature and overmature trees or groups of trees. Harvesting is limited to removing trees having a minimum diameter of 46 cm to ensure that the residual stand will have sufficient trees in the intermediate diameter classes to form the next crop. No prescriptions for silvicultural treatment are given in the management plan beyond the following provisions:

'To meet the needs of silviculture no harvested blocks (or compartments) declared closed to logging will be re-entered. To ensure that as little damage is done to the advanced regeneration as possible, a list of liquidable damages resulting from careless logging is drawn up. The management plan also provides for the breaching of dams to streams caused by tractor tracks and logging roads as experience has shown that damming of streams resulted in the rapid deaths of trees in the residual stand through root damage'.

3.6.6 Summary

Because of its size relative to the other forest types and the fact that the wood resource for the other types is slowly being depleted, the mixed dipterocarp forest is progressively assuming much greater importance than before. It is now the main focus of management attention. Little however is known about this forest type. The prediction of future yields for the various silvicultural options which have been implemented experimentally over the last decade in this forest type is therefore of considerable importance.

CHAPTER 4

SILVICULTURE RESEARCH IN SARAWAK

Prior to 1970 permanent sample plots had been established in virgin stands growing on different parent materials. These plots were infrequently measured, many of them being located in remote areas and were mainly concerned with the study of forest-site relationships. Details of these plots are available in Ashton (1973) and Baillie (1978).

Sustained logging began in Sarawak in the mid sixties and the first permanent mixed dipterocarp forest was not licensed for logging until 1969. For this reason, silvicultural research in the mixed dipterocarp forest has a fairly short history, starting on a significant scale as recently as 1970. The research programme initiated at that time began to examine the development of cutover stands.

Initially, the silvicultural research was concerned with the diagnosis of silvicultural conditions of the forests after logging and with establishing whether the residual stand needed silvicultural treatment (Forest Department, 1970). Based on the recommendations contained in the Silviculture Research Programme 1971-1975 (Forest Department, 1970), a major silvicultural experiment was established to 'determine the effects of four poison-girdling treatments on the regeneration of logged-over mixed dipterocarp forests' (Lee, 1971). Research Plot 68 (under Investigation 47) was set up as a part of this programme. This Research Plot is more fully described in Section 4.1.1.

Technical assistance was requested from the FAO to develop guidelines for silviculture and management and this resulted in the initiation of work on a Silviculture Research Programme.

During the initial phase of the programme, a study entitled 'Guidelines 1' was carried out in selected pilot areas. The Guidelines 1 study made a detailed examination of the species composition and physical structure of the forest to observe and quantify the following:

(a) trends in the frequency and distribution of trees, saplings and seedlings;

(b) the effects of logging upon the forest, particularly with regard to damage and decay evident in surviving trees, the release of immature trees, and the provision of open space for regeneration;

(c) the structure and species composition of the residual forest.

The results of the Guidelines 1 study (Hutchinson, 1977) showed that:

(a) the residual stand contained useful numbers of trees of desirable species which, with silvicultural treatment, were capable of producing a harvest on a short felling cycle;

(b) as long as selective harvests remained of moderate intensity, the mixed dipterocarp forest could be expected to maintain naturally the regeneration of sufficient stems of desirable species to warrant silvicultural treatment and management of the natural forest, neither enrichment nor replacement plants being necessary;

(c) the highest incidence of regeneration of desirable species occurred in the residual stand, supporting the hypothesis that the most rewarding type of silvicultural treatment would be one which retained a forest canopy;

(d) over a simulated time span of 20 years most trees, except large ones with the poorest crowns, were seen to react positively to release resulting from logging.

Hutchinson's work lacked definitive data on stocking and rates of growth and his conclusions involved many assumptions. However the promise of a positive response to silvicultural treatment was sufficiently good to warrant experimental trials of various treatments which maintained forest canopy but provided openings to enable the development of regeneration and advance growth. Research Plots 90 and 102 were established to investigate these treatments and are described in more detail later.

Hutchinson introduced a technique called 'Liberation Thinning' as an experimental treatment. The technique applied in Sarawak was first outlined by Wadsworth (1969). Among the stems which survive logging, it seeks to locate as many trees as possible of 'listed' species, and to liberate the best of them from competition from trees of lesser value. Hutchinson believed that liberation thinning would ultimately promote a shelterwood system of management. Liberation thinning does not seek to eliminate any particular species or group of species. The only trees to be removed are those which restrain the growth of a selected crop tree. Trees of undesirable species which do not compete with crop trees are left untouched. Species diversity is protected and the forest retains its ability to respond to changes in demand.

4.1 Description of Experiments

4.1.1 Research Plot 68

Description

RP 68 was established in 1971. The objective of the experiment was to 'determine the effects of four poison-girdling treatments on the regeneration of logged over mixed dipterocarp forests'. The 'plot' was divided into two 'subplots' RP 68A and RP 68B. The treatments in each subplot were essentially similar but were based on different species lists. In RP 68A, dipterocarps only were considered whereas in RP 68B, the desirable species list was extended to include the following:

Botanical name	Vernacular	Family
Callophyllum spp.	Bintangar	Guttiferae
Cratoxylon spp.	Geronggang	Hypericaceae
Durio spp.	Durian Burong	Bombaceae
Intsia palembanica	Merbau	Leguminosae
Azadirachta spp.	Ranggu	Meliaceae
Sindora spp.	Tampar hantu	Leguminosae

Each subplot is in fact a randomised block with 4 treatments replicated 6 times. Each treatment was applied to a plot of 5 ha and an assessment plot of 1 ha was subsequently established in each treatment plot. The geographical layout of the plot is given in Appendix I.

The treatments were based on the Malayan Uniform System (Section 2.2.1) but the prescriptions had been modified to include retention of advance growth. The treatments were as follows:

1. Control - no treatment applied;
2. Modified Malayan Uniform System (light);
3. Modified Malayan Uniform System (moderate);
4. Modified Malayan Uniform System (heavy).

The distinction between the intensity of treatments was based on the size limit above which undesirable species were removed. A full description of the treatments is given in Appendix II.

Measurement

Initial measurement of RP 68 was carried out in 1972. Each plot was subdivided into 100 10-metre square recording units (Appendix III). Within each unit, a leading tree or potential crop tree was identified. Up to 4 other desirables were identified in the same unit. The following information was recorded for each desirable stem:

(i) species;

(ii) diameter at breast height or above buttress;

(iii) crown position;

(iv) crown form.

All other stems not identified as desirable were tallied in a 10-centimetre class stand table. Details of the measurement procedure are described in Lee and Lai (1977).

RP 68 was measured annually from 1972 to 1975 but only the measurements in 1972 and 1975 have been used in this study in order to reduce the impact of any possible errors of measurement relative to growth over this period.

4.1.2 Research Plot 90

Description

RP 90 was established in 1975 as a result of the findings of the FAO assisted Guidelines 1 study described earlier. It was located in Coupe 5 of the Niah Forest Reserve after logging in 1974.

In this experiment, 5 adjacent logging blocks, each of size 60 ha, considered to be fairly uniform in structure and composition, were selected. One silvicultural treatment, randomly allocated, was applied to each block. The five silvicultural treatments were:

1. Control - no treatment applied;
2. Removal of relics.

   In this treatment, all stems above 60 cm dbh were removed regardless of species.
3. Liberation thinning 20-59 cm dbh.

   Silvicultural thinning to favour potential crop trees in the 20-59 cm diameter class.
4. Liberation thinning 15-59 cm

   Silvicultural thinning to favour potential crop trees in the 15-59 cm diameter class.
5. Liberation thinning 10-59 cm

   Silvicultural thinning to favour potential crop trees in the 10-59 cm diameter class.

The layout of this plot is given in Appendix IV.

In contrast to the Modified Malayan Uniform System of RP 68, the Liberation Thinning treatment only removes trees interfering with the growth of potential crop trees. The field procedure is detailed in Appendix V. The basal areas retained under each treatment are discussed more fully later.

Measurement

In each treatment, 6 enumeration plots were randomly selected within a central core of 30 ha to avoid edge effects (Appendix IV). Each enumeration plot was 1 ha in size, being a square of 100 m. The plot was further divided into 10-metre recording units as for RP 68. The layout follows exactly that of RP 68 (Appendix III). In contrast to the measurement of RP 68, much more information was recorded during the assessment of this Research Plot. The procedure for field measurement is detailed in FAO (1978).

Within each unit, all stems greater than 10.0 cm dbh were identified as far as possible and numbered in order of enumeration. For each stem greater than 10.0 cm, the following information was recorded:

1. Consecutive identifying number
2. Stem identity class
3. Vernacular name
4. Wood quality group
5. Botanical code
6. Silvicultural treatment code
7. Diameter breast height over bark
8. Crown description (illumination and form)
9. Stem lean
10. Tree stability
11. Injury and decay
12. Log grade
13. Woody grade.

The following additional information was recorded for potential crop trees:

1. Upper stem diameter
2. Stem height
3. Total tree height.

Regeneration sampling was carried out within the Research Plot but the data were not utilised in this study. A copy of the field recording form is given in Appendix VI.

RP 90 was measured in 1976, 1977 and 1979. Only data from the 1976 and 1979 assessments have been utilised in this study.

4.1.3 Research Plot 102

Description

RP 102 was established in 1977 as an extension of RP 90 in order to compare the response to liberation thinning with that of the Modified Malayan Uniform System in the same locality.

In RP 102, five silvicultural treatments were tested using a randomised block with 4 replicates of each treatment. The treatments were as follows:

1. Nil treatment control
2. Liberation thinning 15-59 cm dbh
3. Liberation thinning 10-59 cm dbh
4. Modified Malayan Uniform System (light treatment)
5. Modified Malayan Uniform System (heavy treatment).

Each treatment was applied to an entire logging block in the Sawai Protected Forest covering a square approximately 65 ha in area. The layout of this Research Plot is shown in Appendix VII.

Measurement

In RP 102, each assessment plot was 50 by 50 m in dimension (0.25 ha). All assessment plots were located within a central core of 600 by 600 m. This square was subdivided into 4 quarters and from the 36 possible assessment plots one was randomly selected for measurement. Each assessment plot was subdivided into 50 10-metre square quadrats (Appendix VIII). The enumeration procedure for this Research Plot follows exactly that for RP 90. These 4 assessment plots were amalgamated and considered as one single assessment plot of 1 ha for the purpose of this study, as will be described later.

The Research Plot was assessed in 1977 and 1979, and data from both these assessments have been used in this study. The data for Treatment 3 of this RP were missing on the computer tape due to error. Hence, this treatment was not included in this study.

4.2 Data Preparation

4.2.1 Species aggregation

During the measurement of RP 90 and 102, the species were aggregated into 8 Wood Quality Groups (WQG) as follows.

WQG	Description
1	Desirable species - species of current commercial value
2	Acceptable species - species considered to be of future commercial value
3	Non-weed species that grow to timber size (50 cm dbhob)
4	Non-weed that will not grow to timber size
5	Unidentified species
6	Shade tolerant weed species
7	Light demanding weed species
8	Palms.

In the estimation of growth data in this study, the species were further aggregated into 2 groups, crop trees and non-crop trees as follows:

Crop trees

1. Dipterocarp desirables (WQG 1, subgroup 1)
2. Non-dipterocarp desirables (WQG 1, subgroup 2)
3. Acceptable species (WQG 2).

Non-crop trees

All other wood quality groups.

4.2.2 Variables used in the study

Computer programs have been written during the study to provide estimates for variables of interest. Care has been taken to edit the data and to correct errors where possible. Plots with serious errors which could not be corrected were eliminated from consideration.

There are two principal variables of interest in this study, basal area and volume. In estimating basal area and volume, the question arose as to whether to use net measure or gross measure. It was recognised that mortality occurred randomly often as a result of unnoticed logging damage or random events such as storms, droughts, disease, insect attacks, illegal felling and other factors unrelated to experimental treatments. The use of net measures would incorporate confounding effects due to mortality largely unrelated to the experimental treatments and differences between them. It was therefore decided to use gross measures in the study.

4.2.2.1 Basal area

The basal area for non-desirable or acceptable species in RPs 68A and 68B were computed using the program BASALAREAS 5 developed by the Department of Forestry, University of Oxford. The program computes basal area from stand tables compiled in broad size classes, as was done in this case. For this Research Plot, the estimates of basal area of non-crop trees are therefore less precise than for the other Research Plots because the stand tables were compiled in 10 cm diameter classes, the actual diameter only being measured in the case of potential crop trees. The basal areas for all potential crop trees were computed from recorded dbh values.

Gross basal areas of the Research Plots are summarised in Figures 4.1.1 - 4.1.4. Detailed results are in Appendix IX.

Analysis of the first measurement data from all the Research Plots provided estimates of the gross basal area of all stems (including palms) above 10.0 cm dbh in the original stand. The figures show that the total basal areas in the four experimental areas were fairly uniform, ranging from 22.58 to 38.30 sq m per ha.

The basal area removed by logging can be gauged by comparing that in the control replicates with that prior to logging. The basal areas and percentage of basal areas removed are shown in Table 4.1.

Table 4.1 highlights the variation in logging intensity. In general a greater basal area was removed from RP 68A and RP 68B than from either RP 90 or 102. One replicate in RP 68B showed as much as 71% basal area removed. The intensity of logging in the mixed dipterocarp forest is generally influenced by the Asian log market. The log market in 1974 and 1976 had been depressed, explaining the low intensity of logging in RP 90 and RP 102.

Figures 4.1.1 - 4.1.4 show differences in the amount of basal area retained under each experimental treatment in the 4 Research Plots. The residual basal area has been further divided into crop trees and non-crop trees basal area. While the contrast between treatments in RP 68A, 68B and 102 are fairly sharp, it is less so in RP 90. The percentage of basal area retained under the 3 Liberation Thinning treatments for instance differ only by about 10%.

Certain unexpected results show up in these data. It was expected that the basal area of crop trees in Treatment 5 of RP 90 would be greater than in Treatment 4 because crop trees down to 10 cm diameter were favoured. But Treatment 4 turned out to be higher on the average.

Figure 4.1.1 Research Plot 68A
Gross basal area (sq m/ha) by treatment

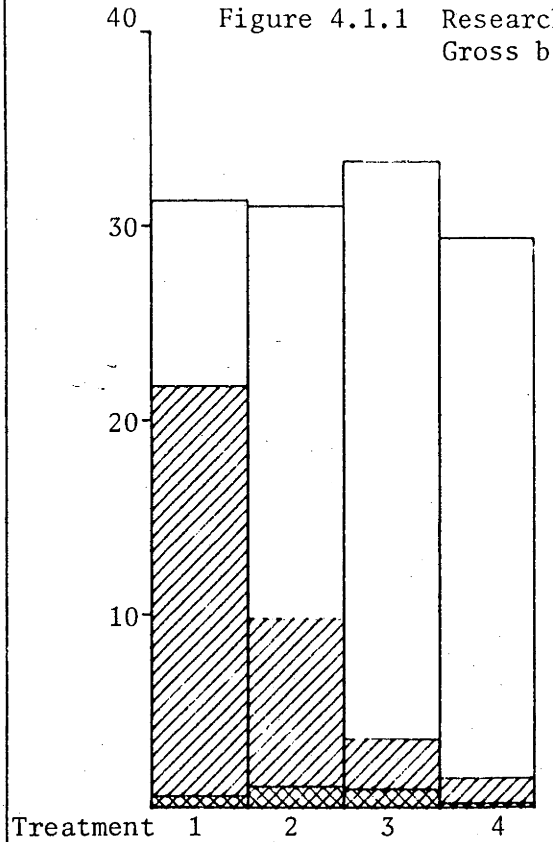


Figure 4.1.2 Research Plot 68B
Gross basal area (sq m/ha) by treatment

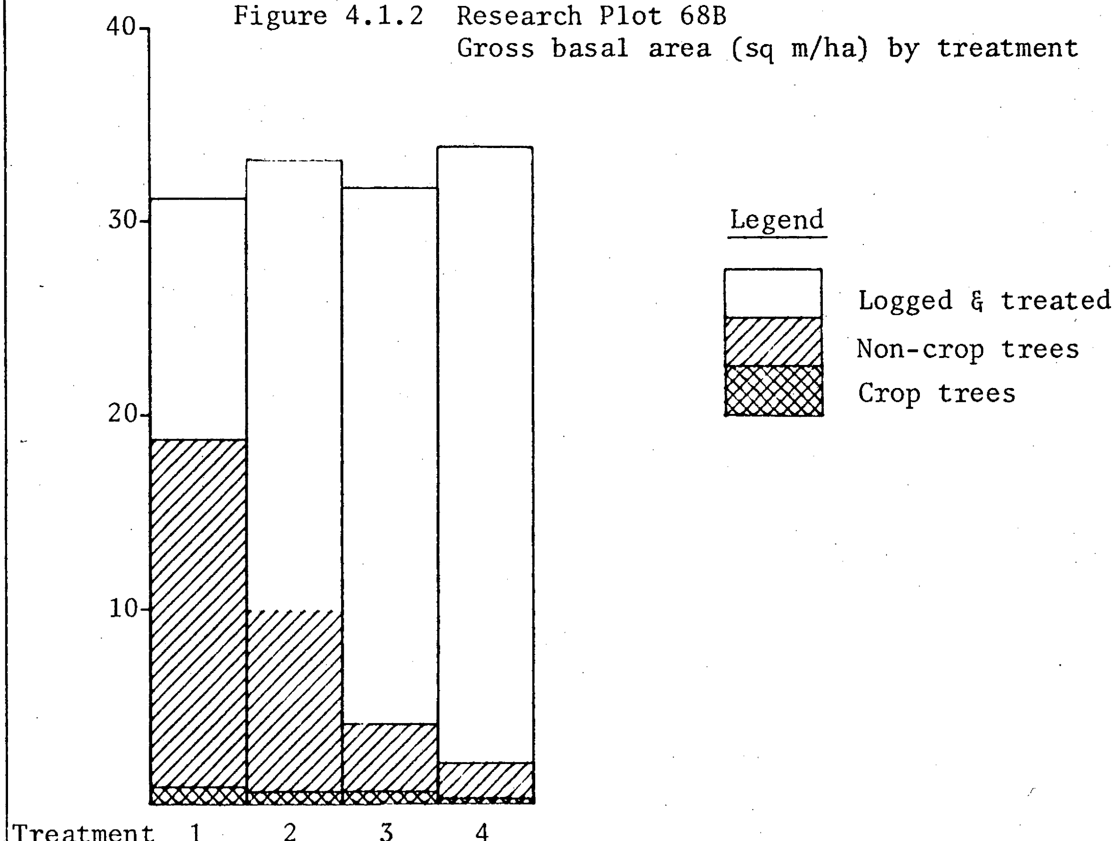


Figure 4.1.3 Research Plot 90
Gross basal area (sq m/ha) by treatment

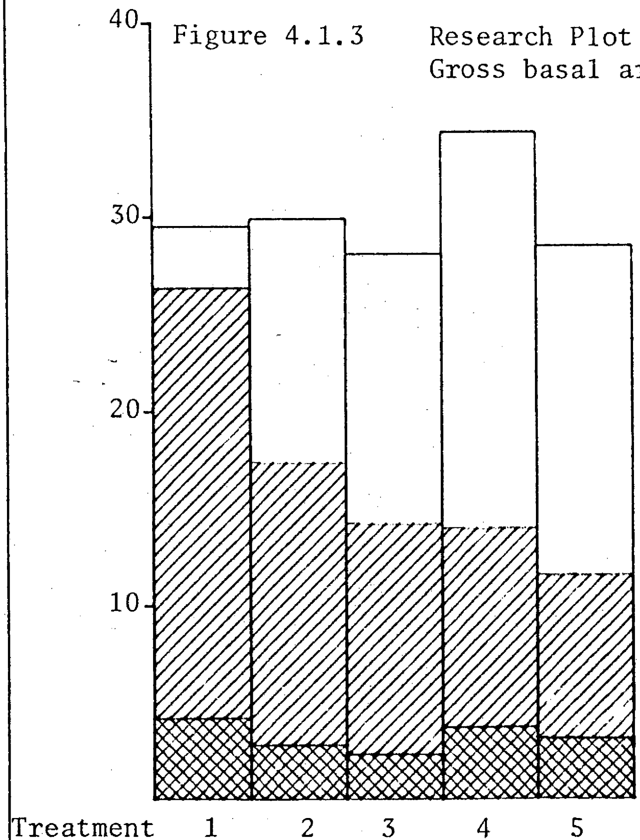


Figure 4.1.4 Research Plot 102
Gross basal area (sq m/ha) by treatment

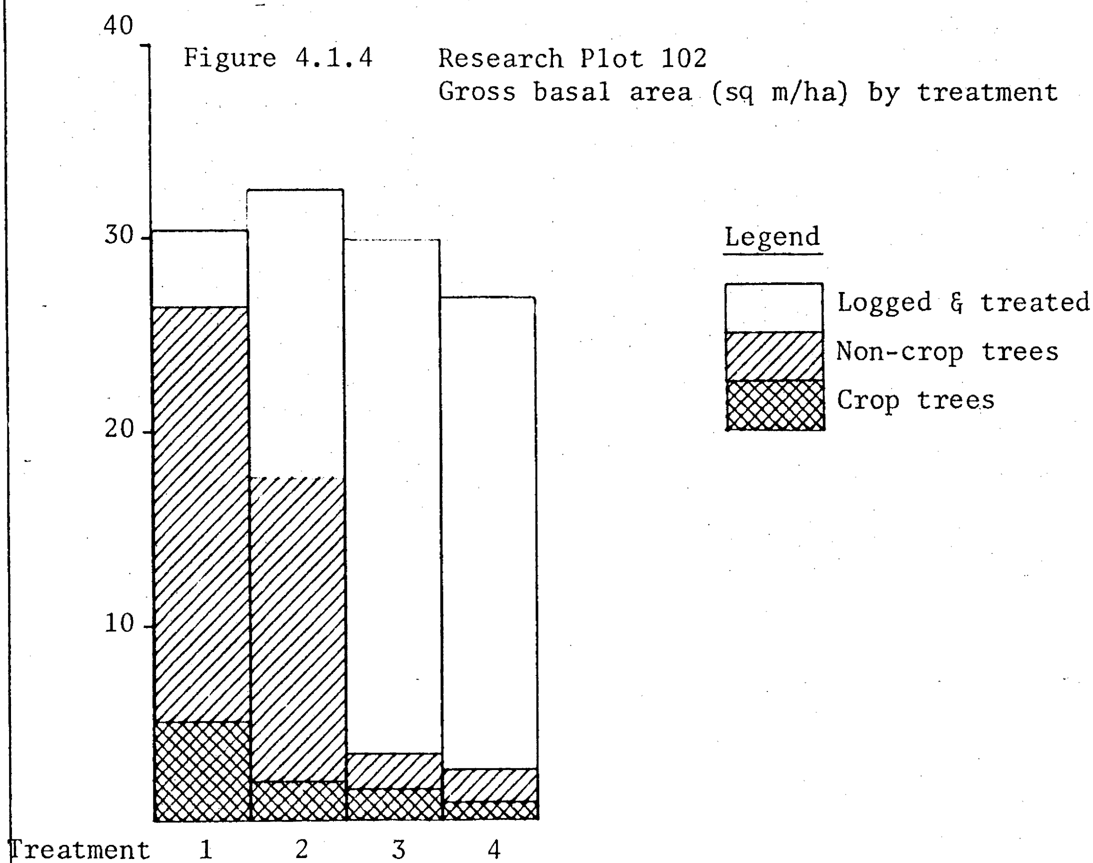


TABLE 4.1 Basal area (sq m/ha) removed by logging (in control replicates only)

Research Plot (year logged)	Rep.	Gross basal area Original stand	Gross basal area after logging	% original b.a. removed
68A	1	29.29	20.80	29.0
(1970)	2	32.40	23.10	28.7
	3	29.80	19.84	33.4
	4	28.00	24.63	12.0
	5	32.32	20.29	37.2
	6	35.95	21.74	39.5
68B	1	28.63	8.06	71.8
(1970)	2	37.67	18.12	51.9
	3	32.76	18.97	42.1
	4	33.28	27.14	18.5
	5	26.79	22.27	16.9
	6	27.75	17.80	35.9
90	1	29.67	27.20	8.3
(1974)	2	30.07	27.21	9.5
	3	28.78	24.62	14.5
102	1	33.91	27.96	17.5
(1976)	2	26.81	22.69	15.4
	3	28.13	24.86	11.6
	4	32.62	30.16	7.5

Treatments 3 and 4 of RP 102 were intended to provide a contrast between light and heavy treatments under the Uniform System. In practice, the basal areas retained in both treatments were similar. In fact, what was defined as 'light' treatment turned out to be the heavier of the two. These unexpected results underscore the variability in stocking and basal area of crop trees in the mixed dipterocarp forests, even though the total basal area of the original forest seems uniform. Figures 4.2.1 - 4.2.4 summarise the basal area of residual crop trees and non-crop trees by treatments. They highlight variations within treatments.

The inclusion of the 7 additional non-dipterocarps in the list of desirable species for RP 68B was intended to gauge whether they contributed significantly to the basal area of the crop trees.

TABLE 4.2 Mean basal area of dipterocarps and non-dipterocarps in Research Plot 68B (sq. m/ha)

Treatment	Dipterocarp	Non-dipterocarp
1	0.808	0.018
2	0.545	0.037
3	0.540	0.053
4	0.228	0.006

Table 4.2 shows that the 7 non-dipterocarp species did not contribute significantly to the basal area.

The proportion of non-dipterocarps to dipterocarps in RPs 90 and 102 has not been examined in this study but is an analysis which should be carried out in the future.

Figure 4.2.1 Research Plot 68A

Residual basal area (sq m/ha) by treatment

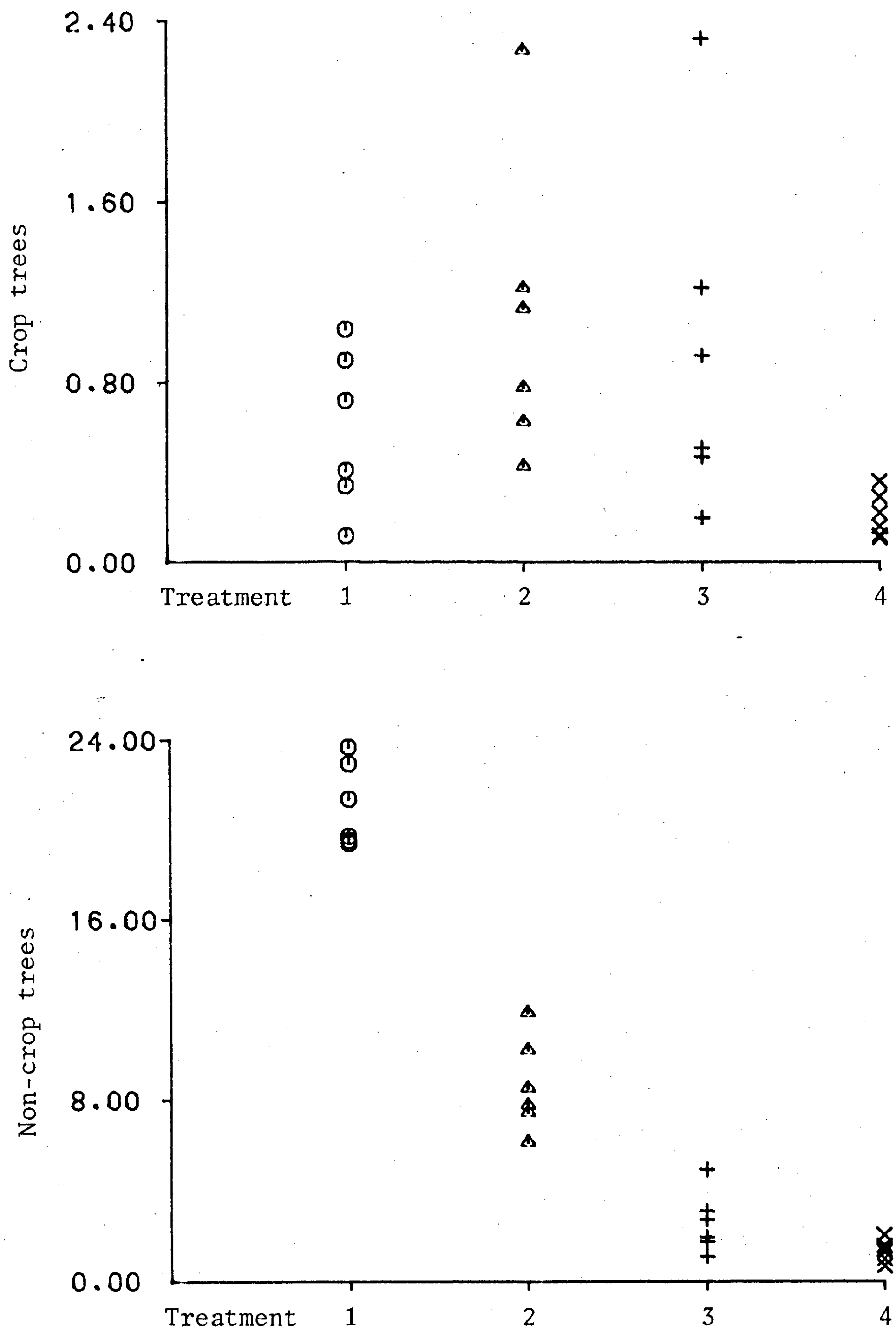


Figure 4.2.2: Research Plot 68B

Residual basal area (sq m/ha) by treatment

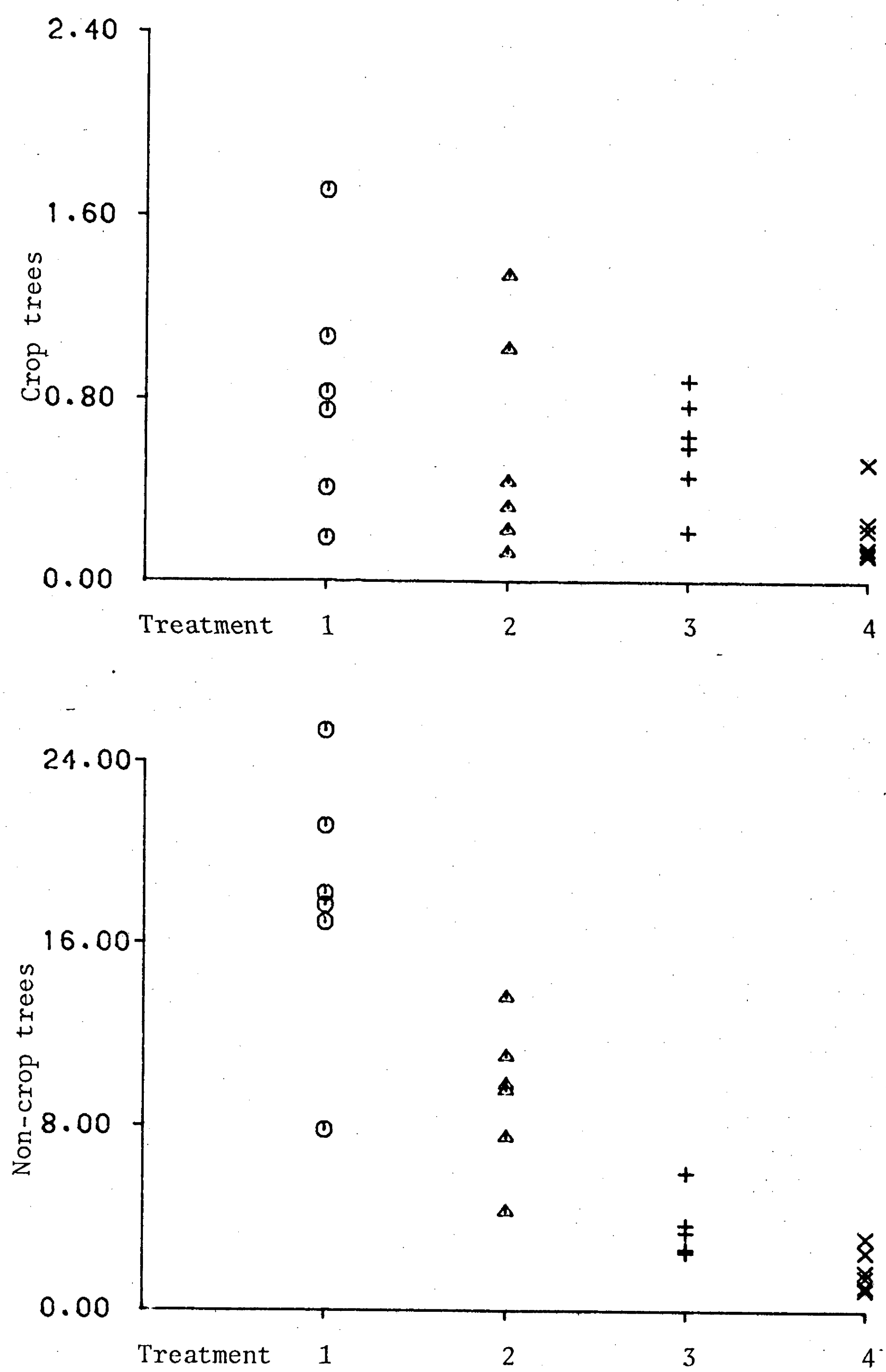
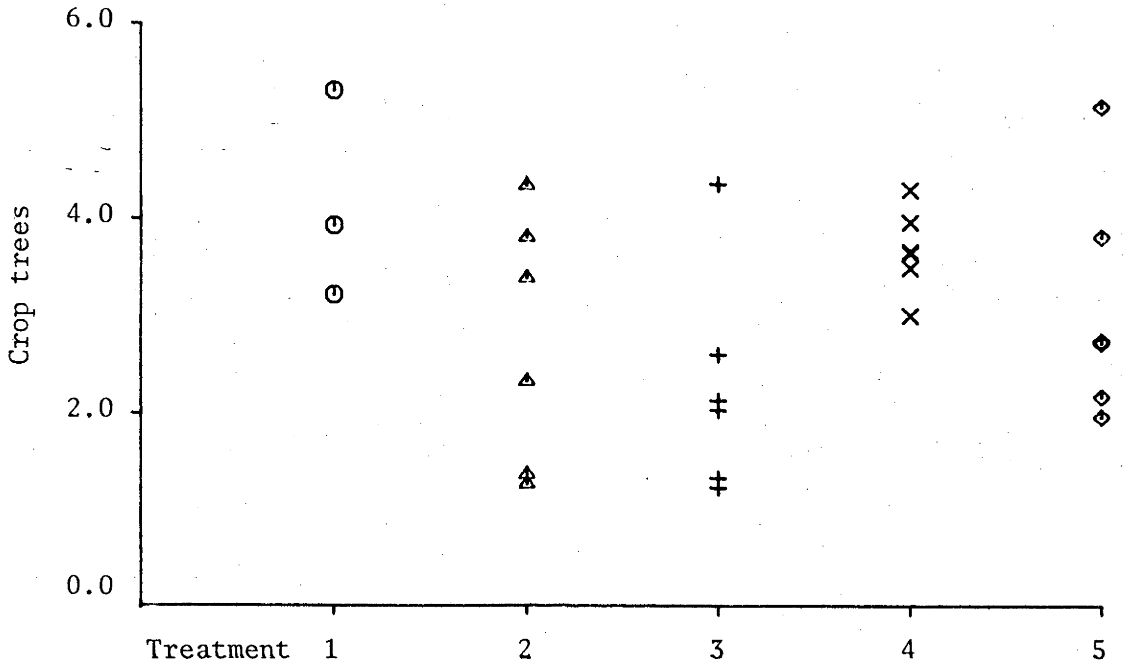


Figure 4.2.3: Research Plot 90

Residual basal area (sq m/ha) by treatment



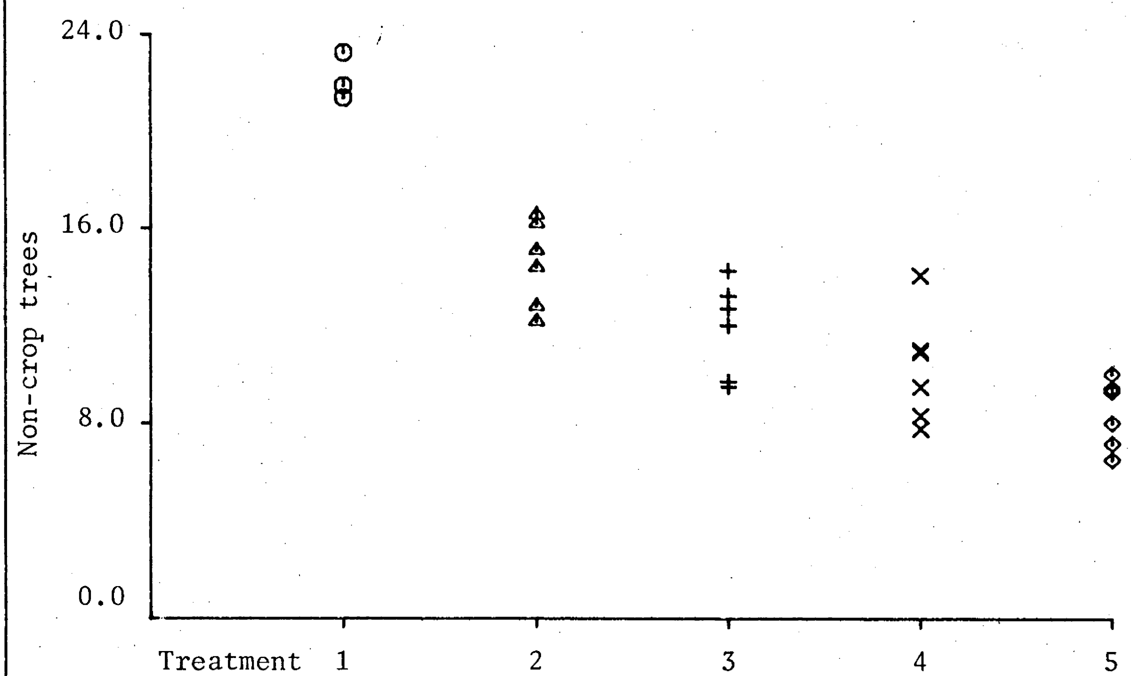
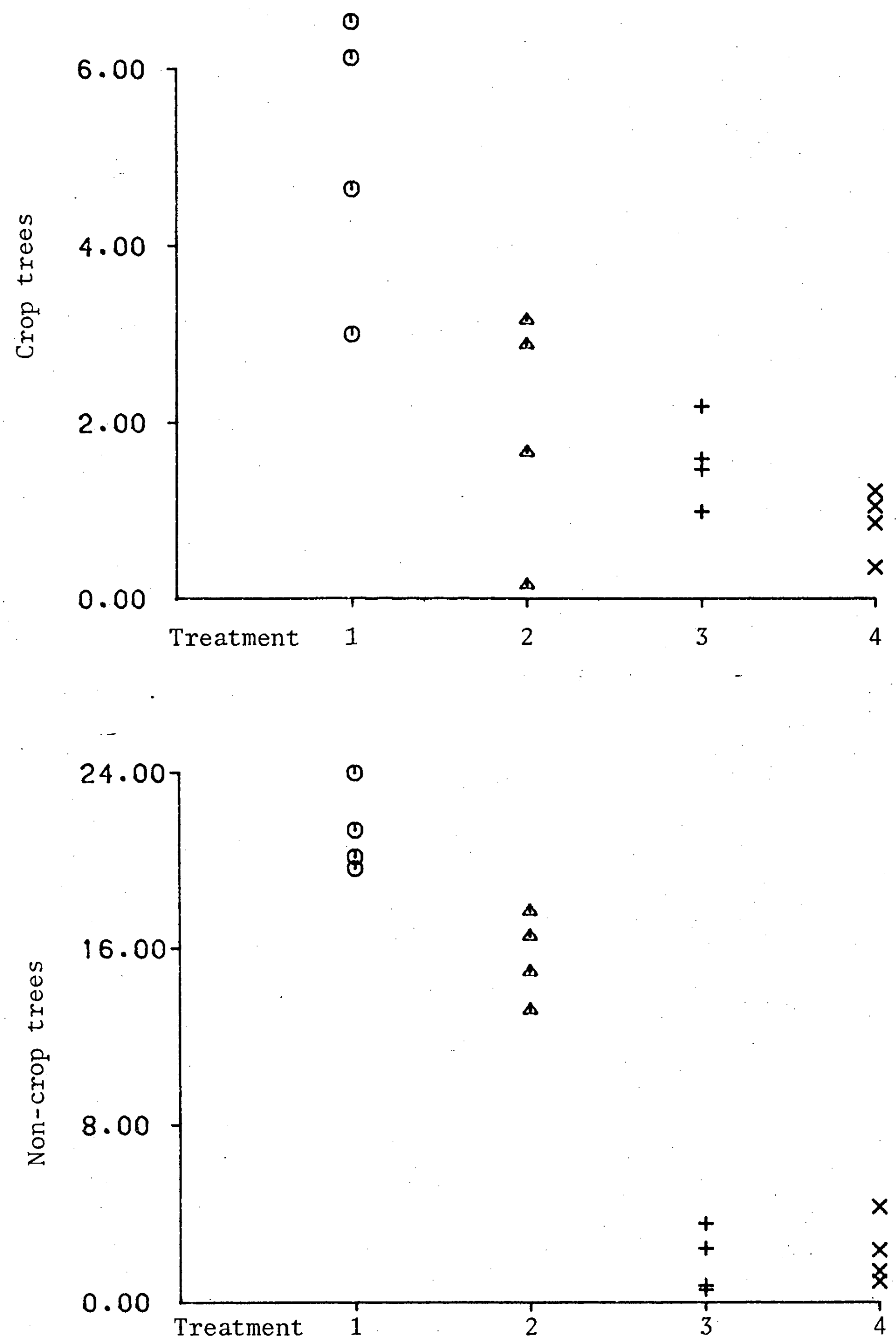


Figure 4.2.4: Research Plot 102

Residual basal area (sq m/ha) by treatment



4.2.2.2 Volume

Several volume equations have been developed following the FAO Forest Inventory Survey (FAO, 1974).

Some of these equations are two-way equations requiring diameter and height information. Because measurements of tree height were not available for data in this study, the following equations from FAO were used.

Volume was estimated only for trees above 20.0 cm. For small trees in the diameter range 20.0 - 45.9 cm, the equation was:

$$V = 0.074 - 0.053D + 0.03D^2 + 0.0024D^3$$

where V = Sound stem volume in cu m

D = Diameter at breast height or above buttress over bark in cm.

For trees larger than 46.0 cm diameter but less than 165.0 cm, the volume equation was:

$$V = 3.8 - 0.47D + 0.1525D^2 - 0.0034D^3.$$

For trees larger than 165 cm, the sound stem volume was assumed to be a constant of 18.97 cu m.

Estimates of the sound stem volume of the residual stand are presented in Figures 4.3.1 - 4.3.4.

On average, approximately 220 cu m per ha of sound stem were left in the residual stand after logging in both RP 90 and RP 102. Crop trees made up 18.4% of this volume in RP 90 and 22.7% in RP 102. In RP 68A, the residual volume after logging was approximately 190 cu m per ha with dipterocarp crop trees making up only about 3%. In RP 68B, the post-logging basal area was 164 cu m per ha with crop trees making up about 5%, most of these being dipterocarps. The increasing intensities of treatment in RP 102 resulted in a progressive reduction in

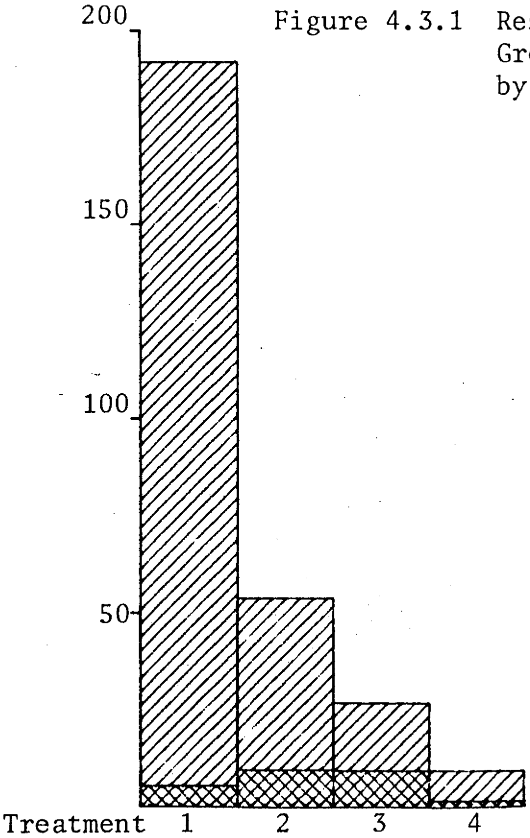


Figure 4.3.1 Research Plot 68A
Gross sound stem volume (cu m/ha)
by treatment

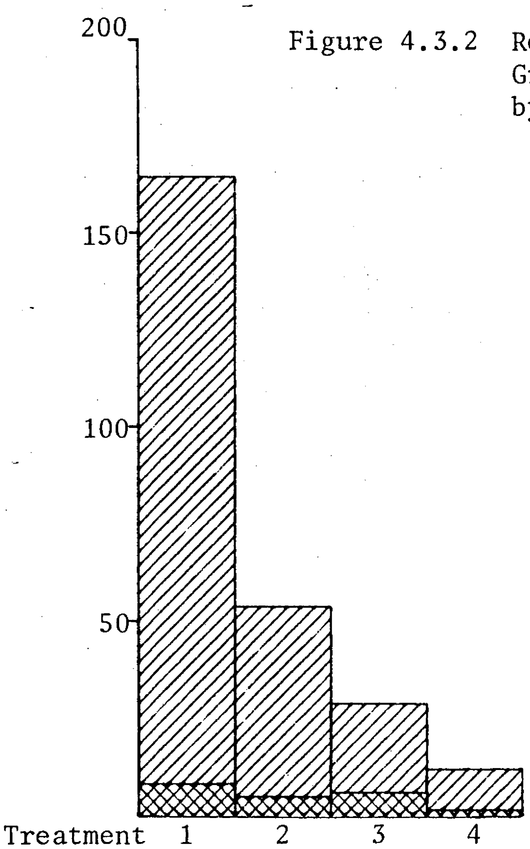
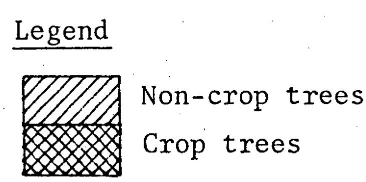


Figure 4.3.2 Research Plot 68B
Gross sound stem volume (cu m/ha)
by treatment



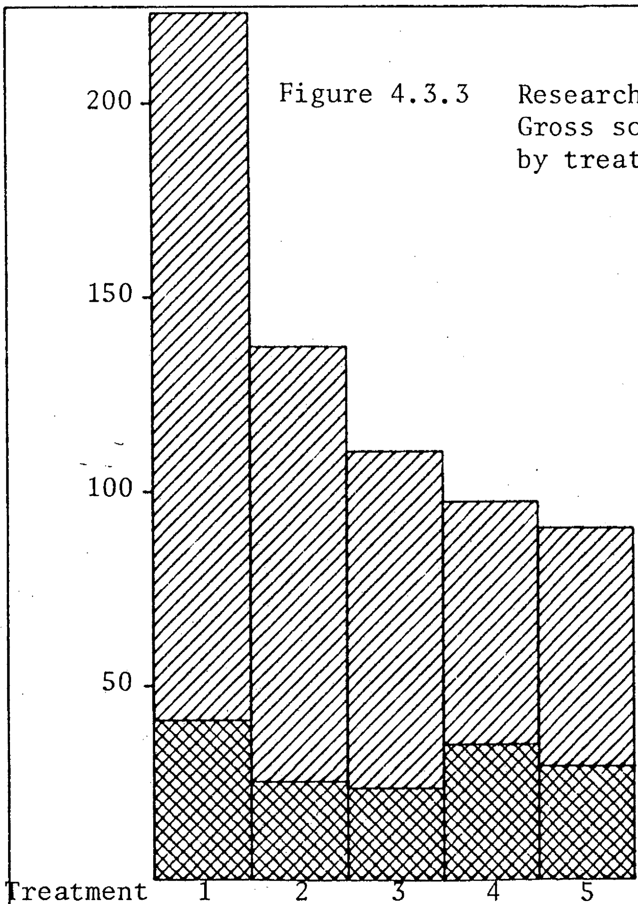


Figure 4.3.3 Research Plot 90
Gross sound stem volume (cu m/ha)
by treatment

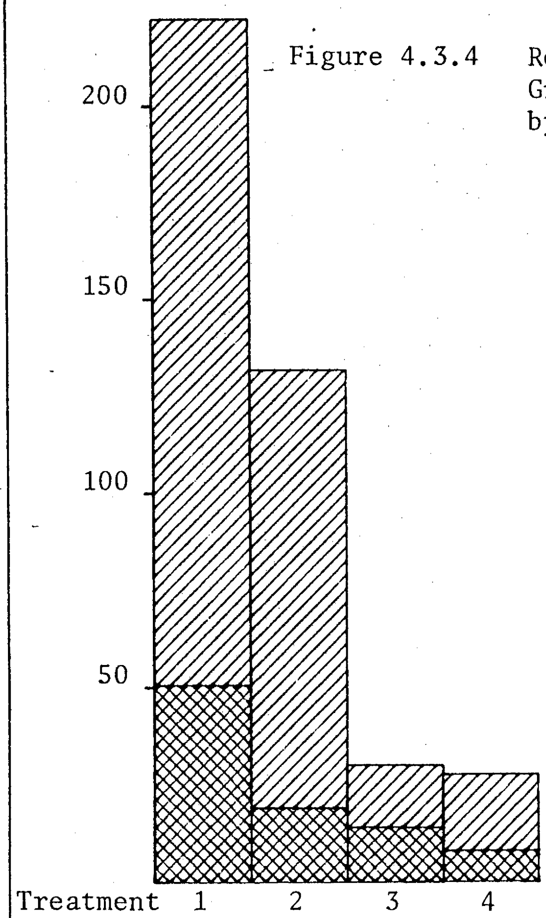
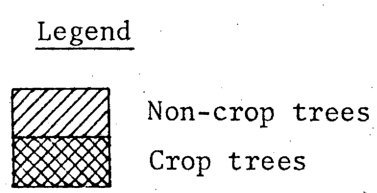


Figure 4.3.4 Research Plot 102
Gross sound stem volume (cu m/ha)
by treatment



residual volume of the crop trees. In the other Research Plots, no such trend was observed. Figures 4.4.1 - 4.4.4 summarise the sound stem volumes of the crop trees and non-crop trees by treatments and show variations within treatments.

Figure 4.4.1: Research Plot 68A

Residual sound stem volume (cu m/ha) by treatment

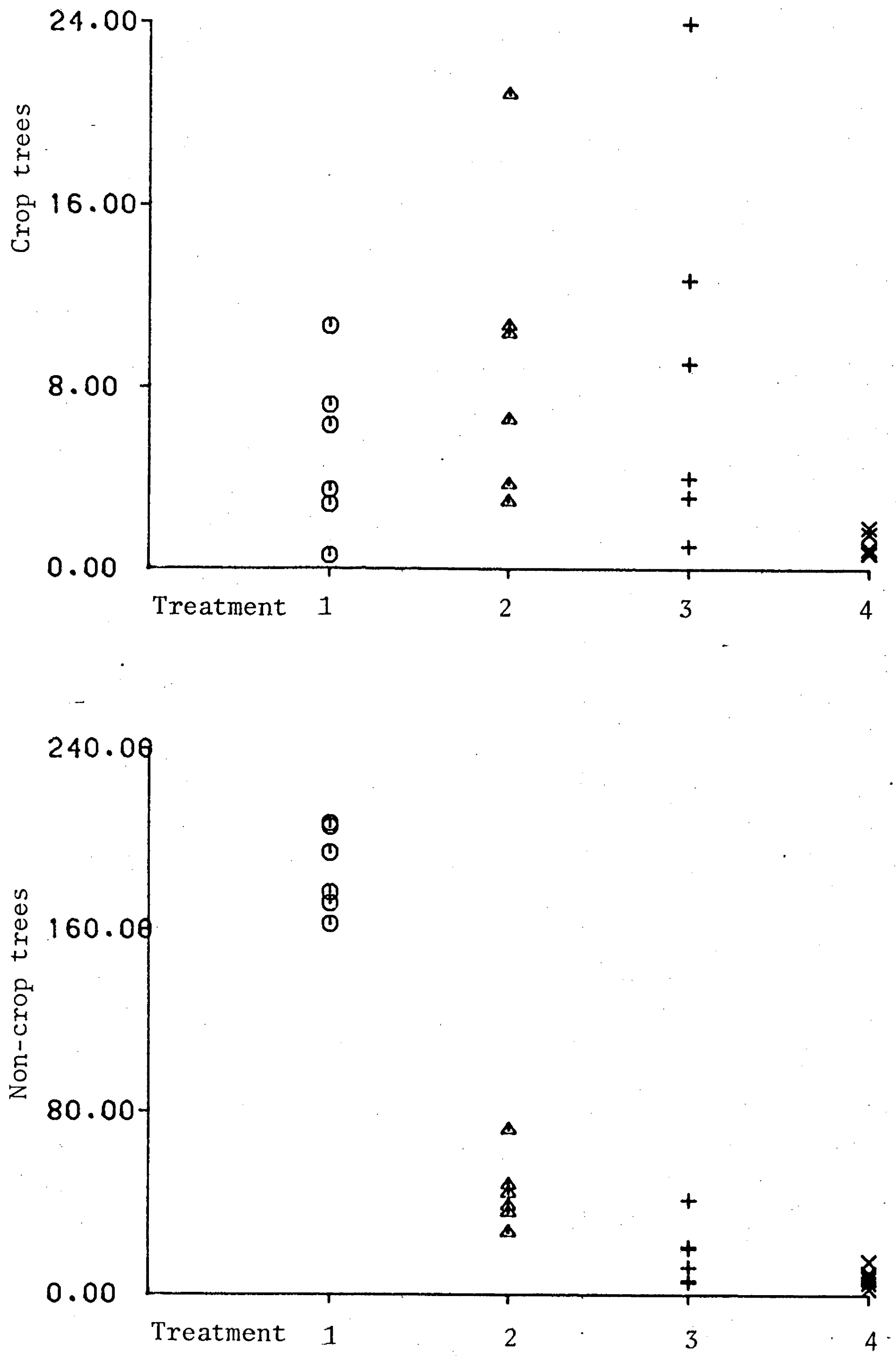
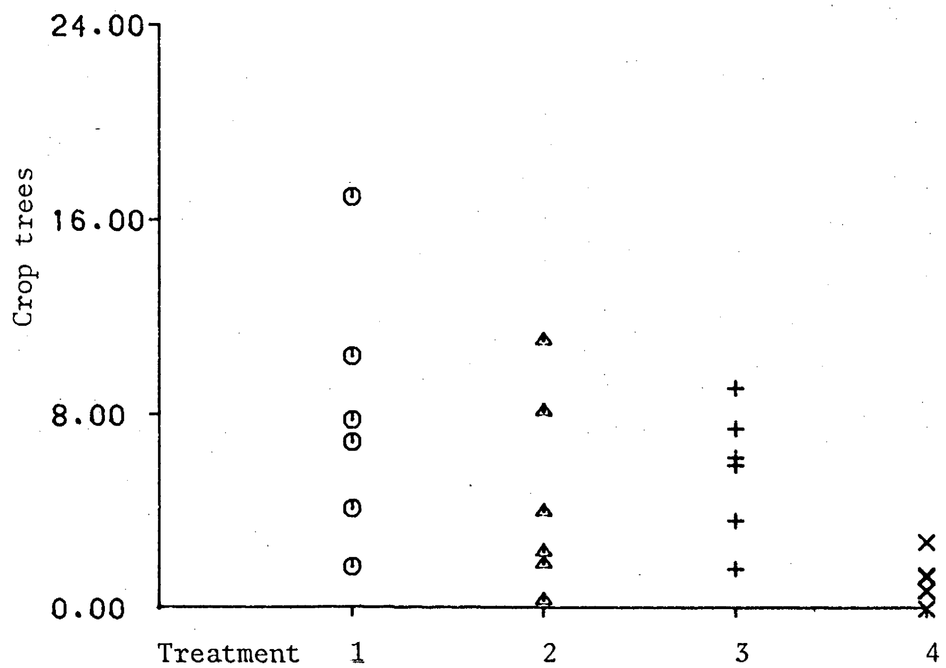


Figure 4.4.2: Research Plot 68B

Residual sound stem volume (cu m) by treatment



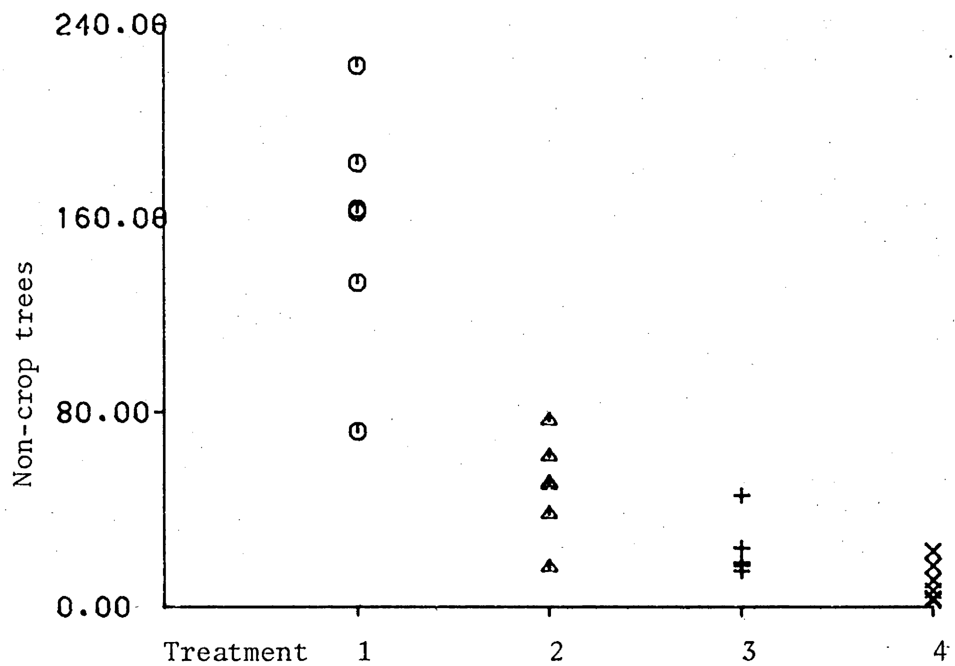


Figure 4.4.3: Research Plot 90

Residual sound stem volume (cu m/ha) by treatment

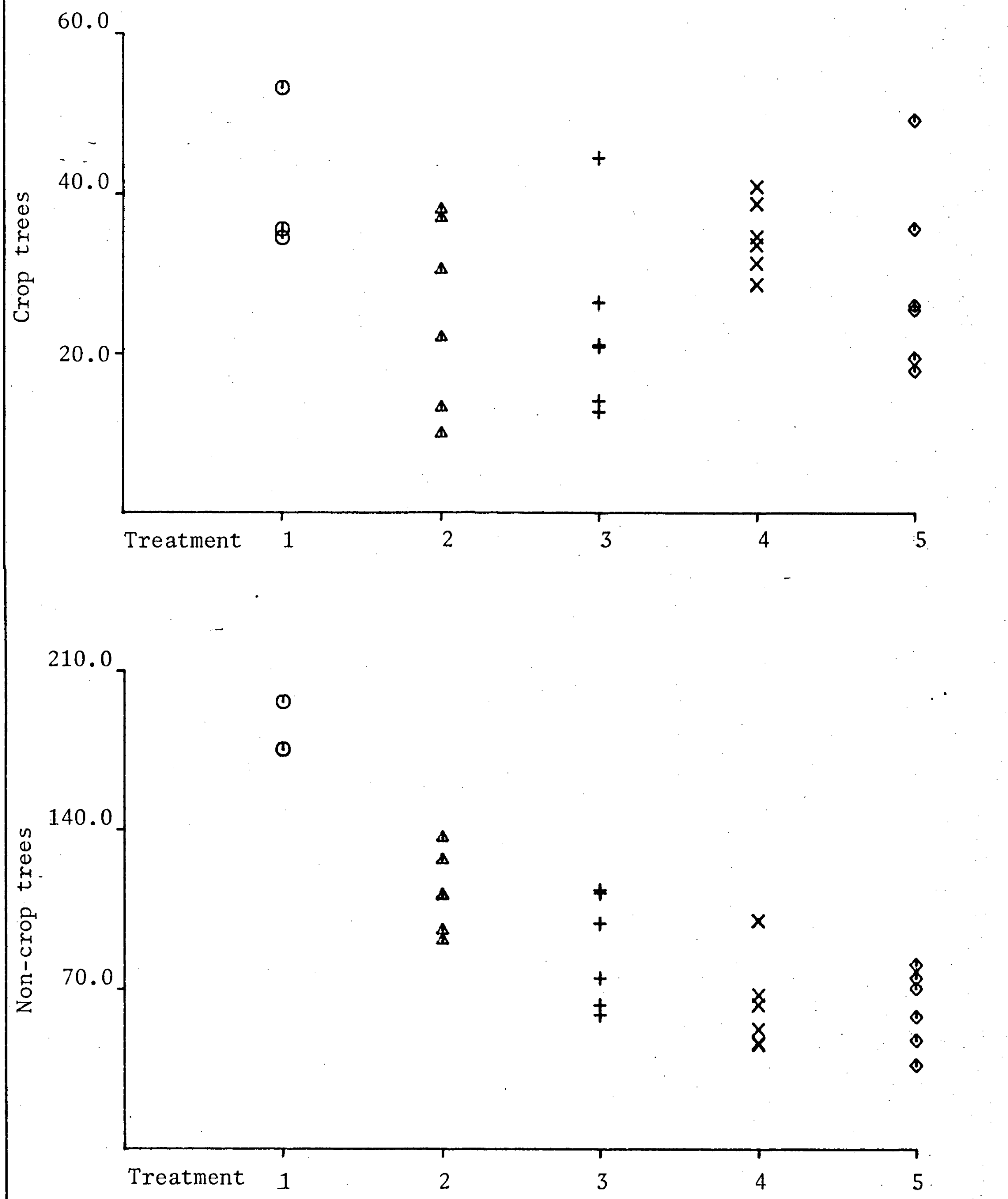
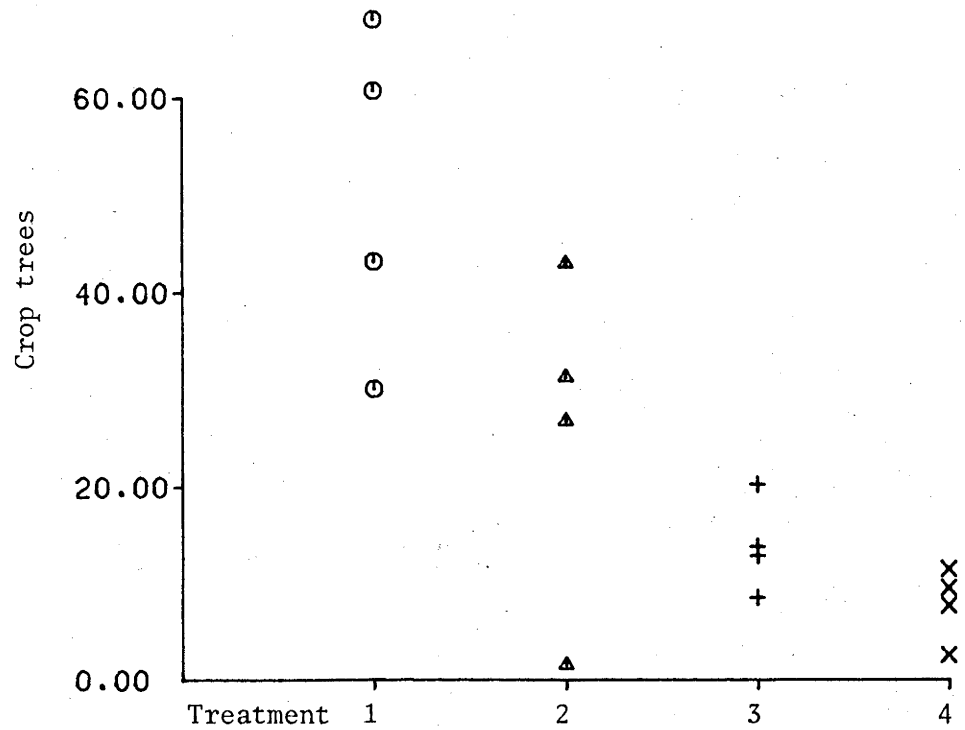
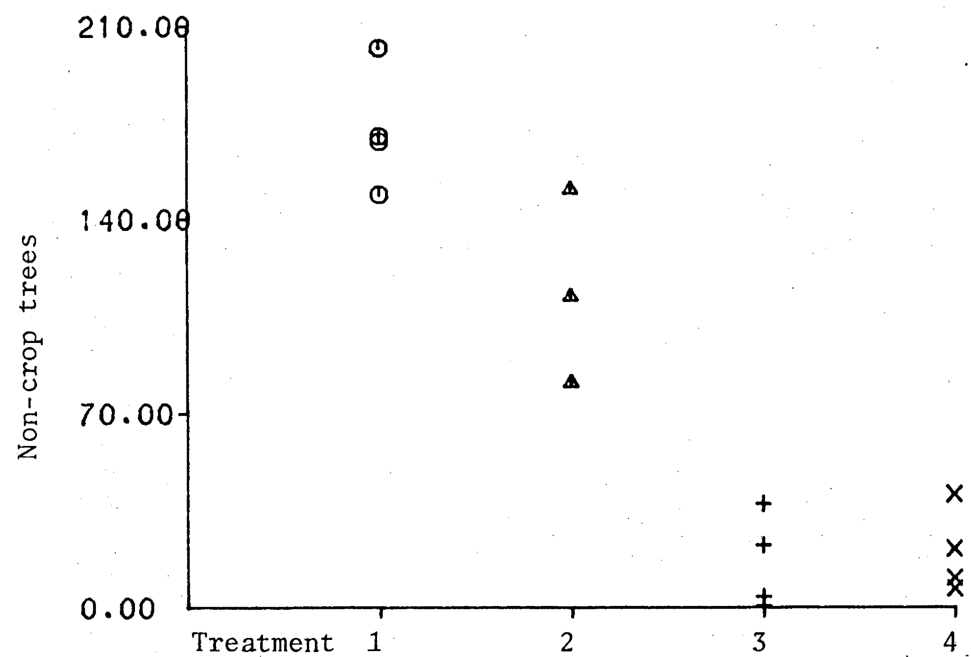


Figure 4.4.4: Research Plot 102

Residual sound stem volume (cu m/ha) by treatment





CHAPTER 5

RESPONSE TO SILVICULTURAL TREATMENTS

The estimates of both the basal area increments and sound stem volume increments were derived from the diameter at breast height of the stems. The response of the forest in terms of gross basal area and volume increments therefore parallel each other. For this reason only the results for gross basal area increment are presented in this chapter. The results of the volume analyses may be found in Appendix XI.

Management decisions are centred around the increments or yields of potential crop trees. It was therefore decided to aggregate species into two broad groups, crop trees and non-crop trees. Further sub-division of crop trees into dipterocarps and non-dipterocarps may also be important because there are substantial differences in stumpages paid for these groups. However, time available during the study did not permit analyses to this level of aggregation.

Gross basal area increments of the various silvicultural treatments are shown in Figures 5.1.1-5.1.4 for the respective Research Plots. The variation of increment within treatments was very high and tends to obscure differences between treatments. Of particular note however is the high increments for Treatment 4 of Research Plot 90 (Figure 5.1.3) involving Liberation Thinning to favour crop trees in the 15-59 cm diameter range.

Gross basal area increments were also plotted against residual basal area of the crop trees and non-crop trees (Figures 5.2.1-5.2.4 and 5.3.1-5.3.4). These figures suggest a general trend of increasing

Figure 5.1.1 : Research Plot 68A

Basal area increment by treatment

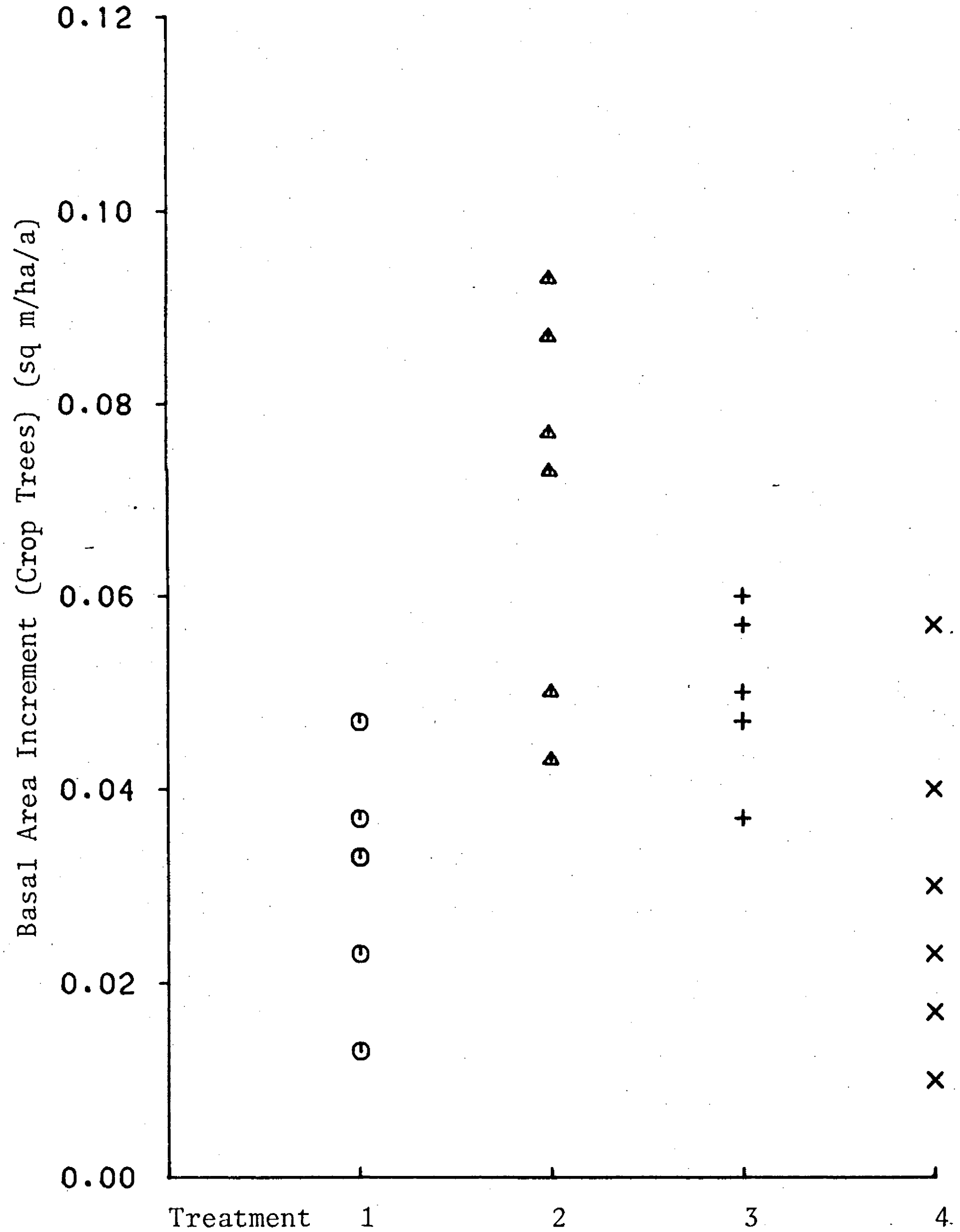


Figure 5.1.2: Research Plot 68B

Basal area increment by treatment

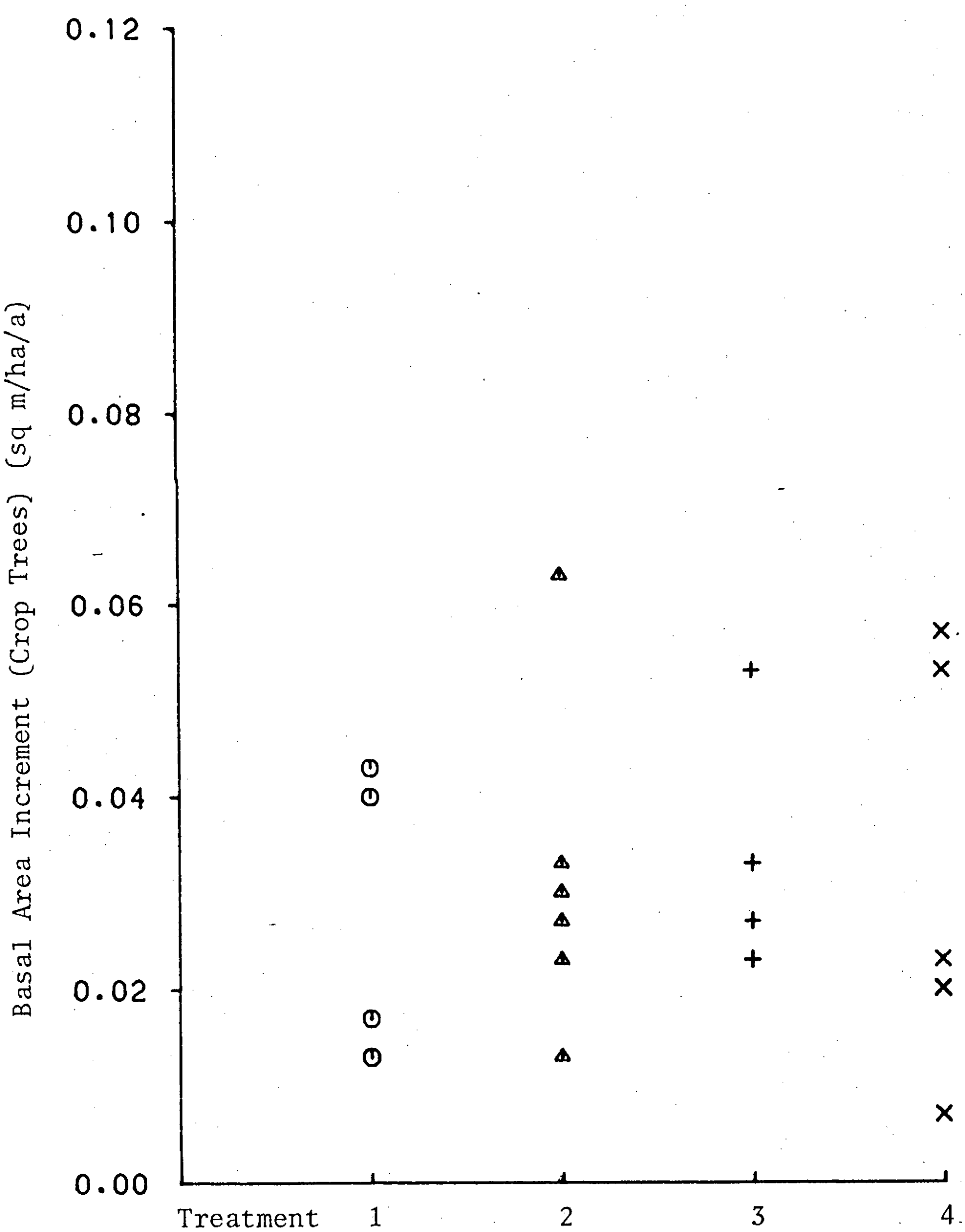


Figure 5.1.3: Research Plot 90
Basal area increment by treatment

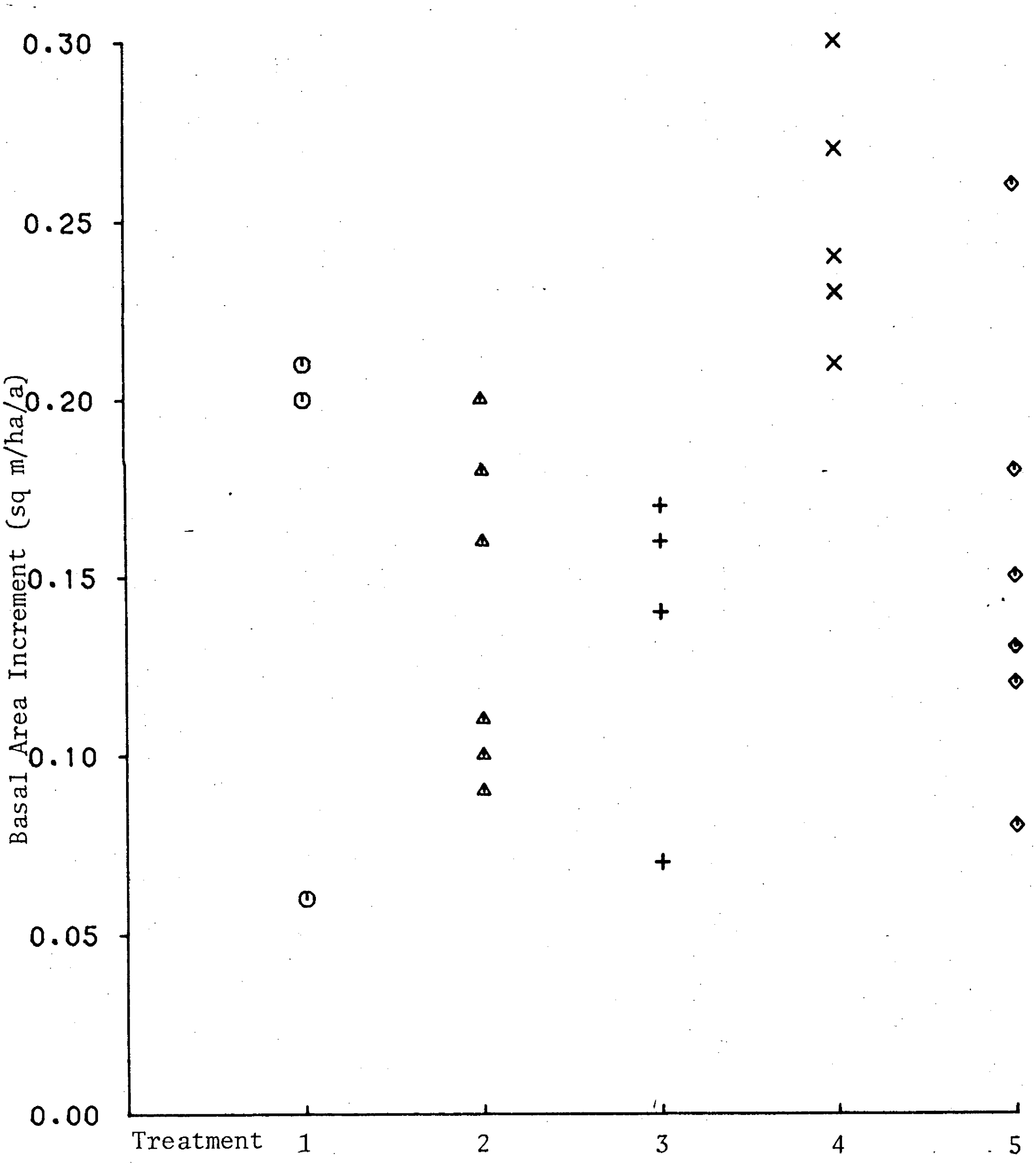


Figure 5.1.4 : Research Plot 102

Basal area increment by treatment

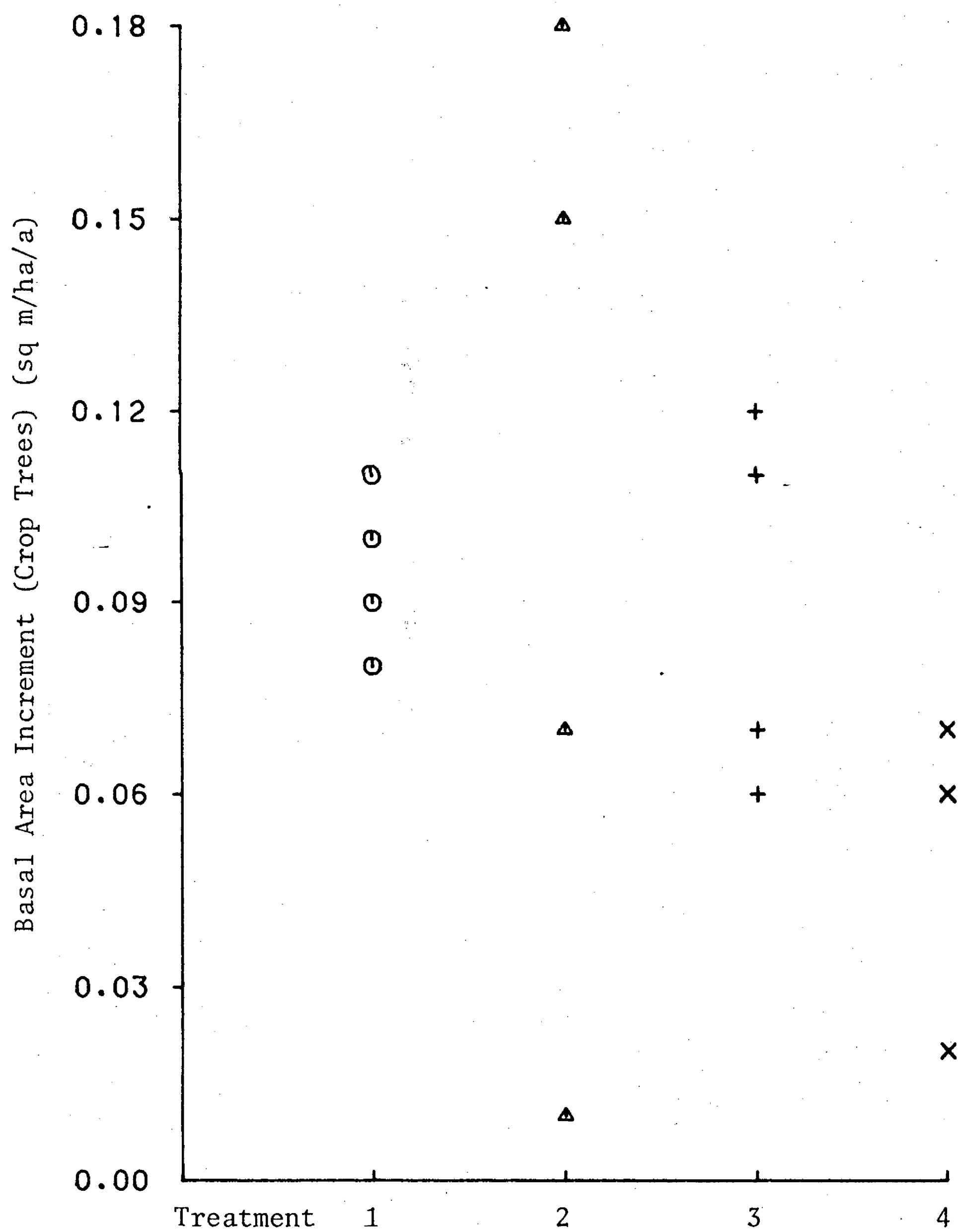


Figure 5.2.1: Research Plot 68A

Relationship between basal area increment and residual basal area of crop trees.

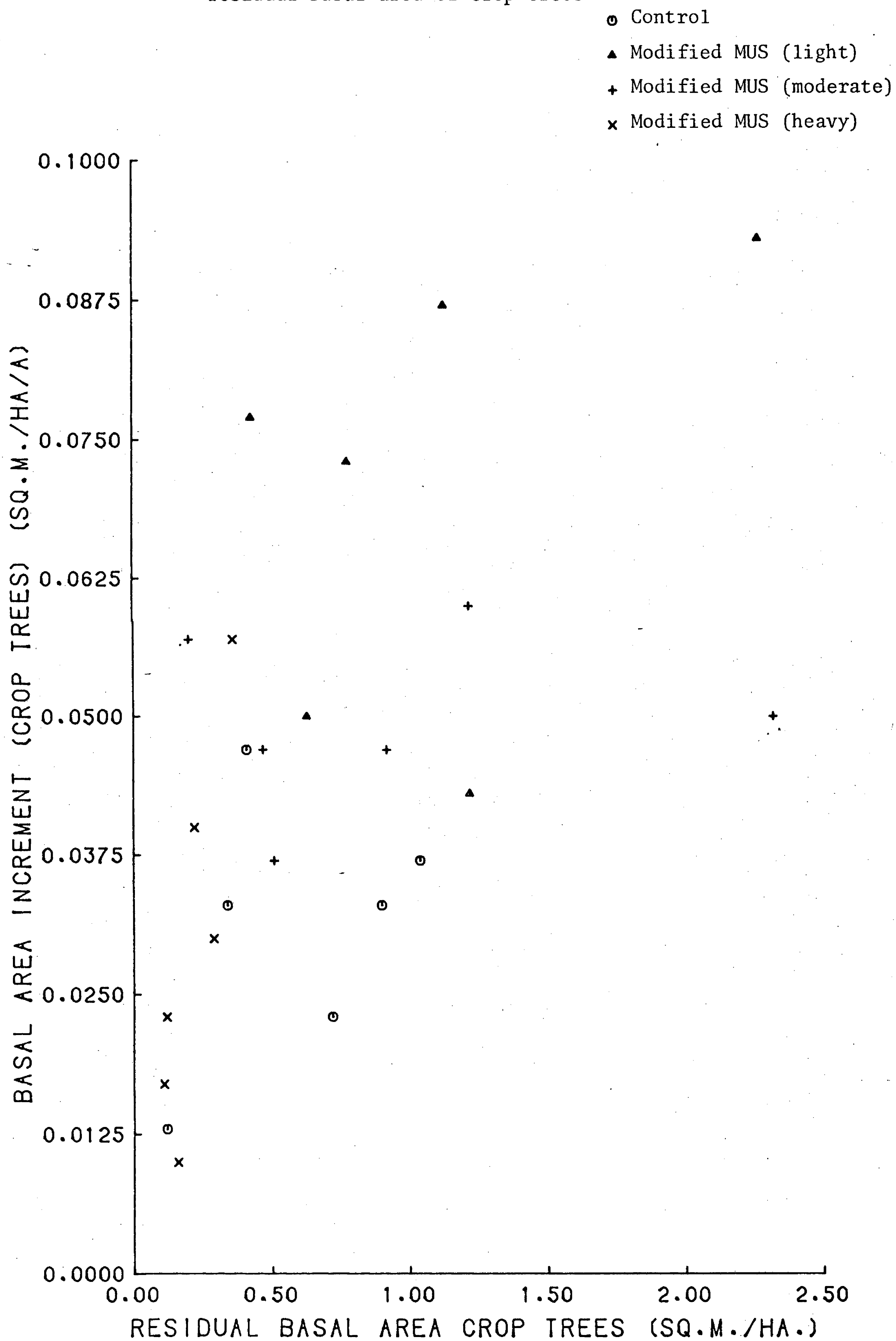


Figure 5.2.2 : Research Plot 68B

Relationship between basal area increment and residual basal area of crop trees

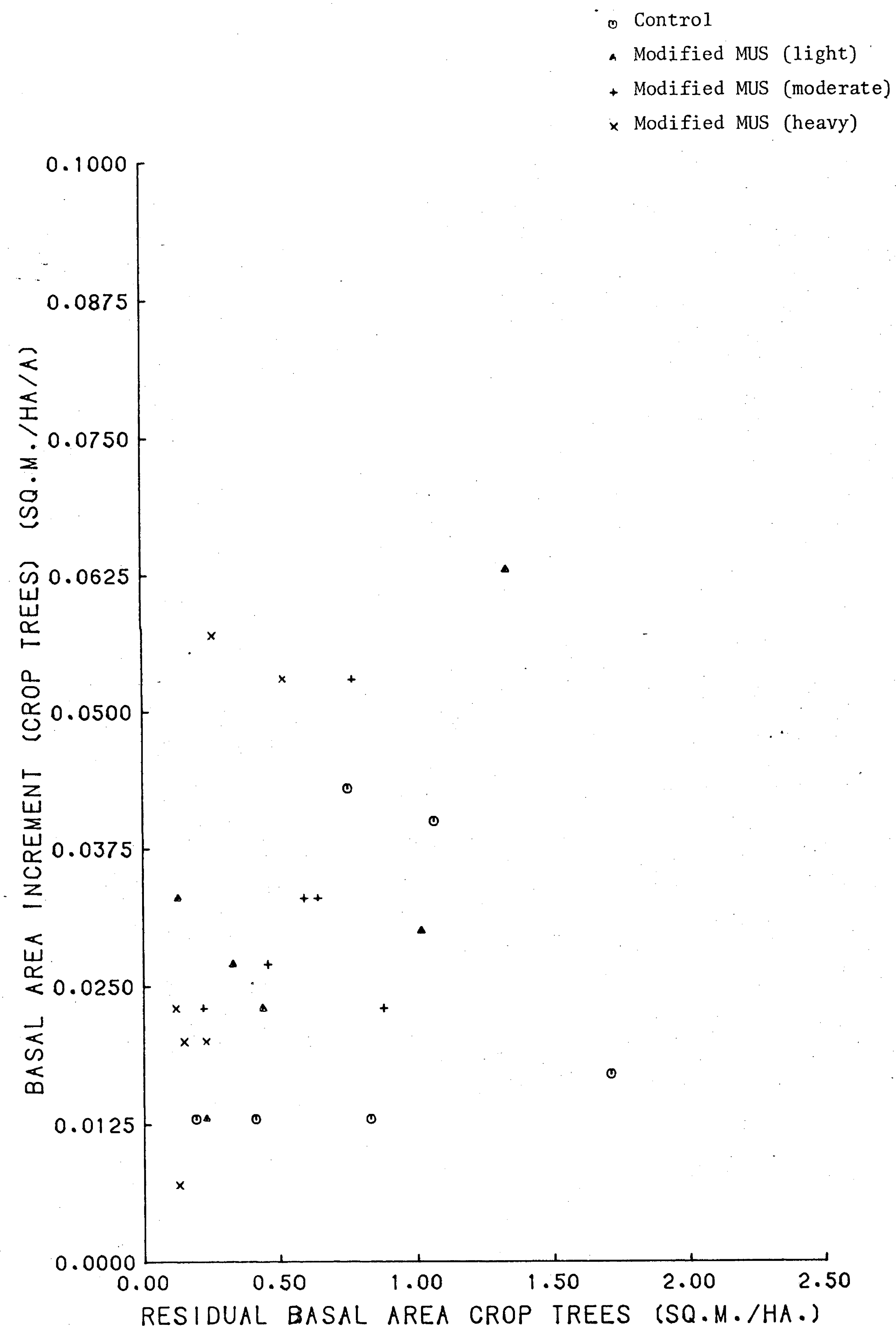


Figure 5.2.3: Research Plot 90

Relationship between basal area increment and residual basal area of crop trees

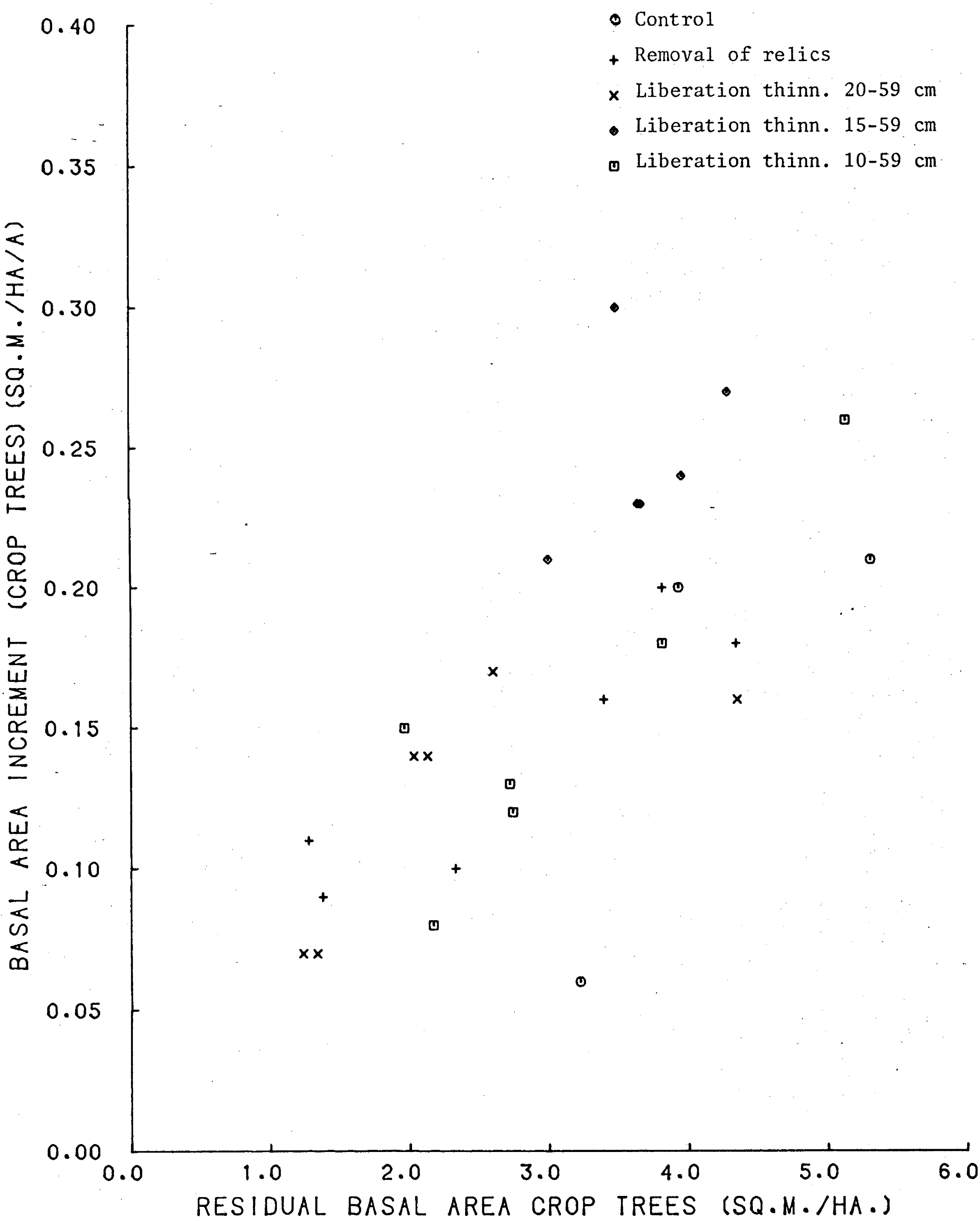


Figure 5.2.4: Research Plot 102

Relationship between basal area increment and residual basal area of crop trees

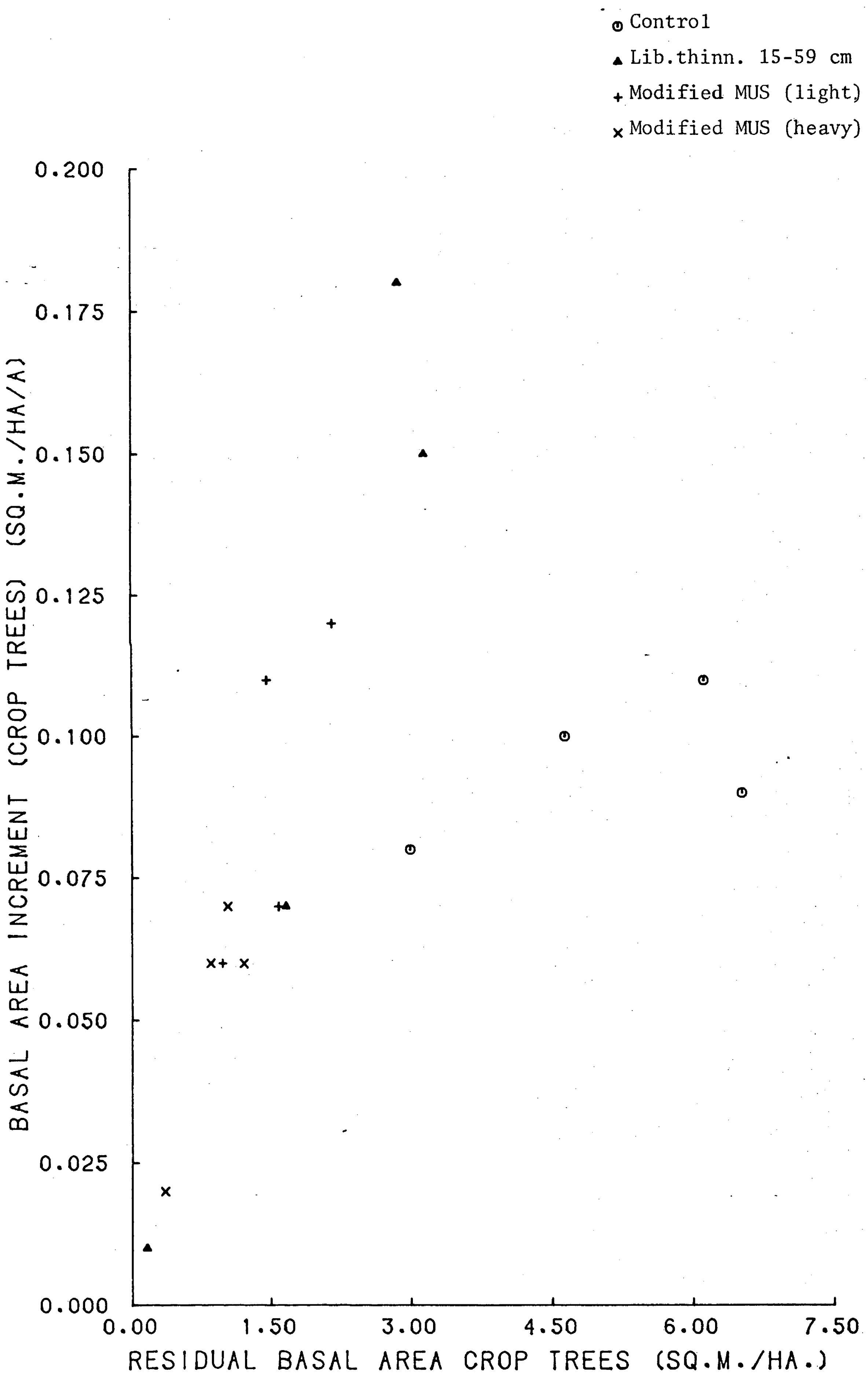


Figure 5.3.1 Research Plot 68A
Relationship between basal area increment crop trees & residual basal area non-crop trees

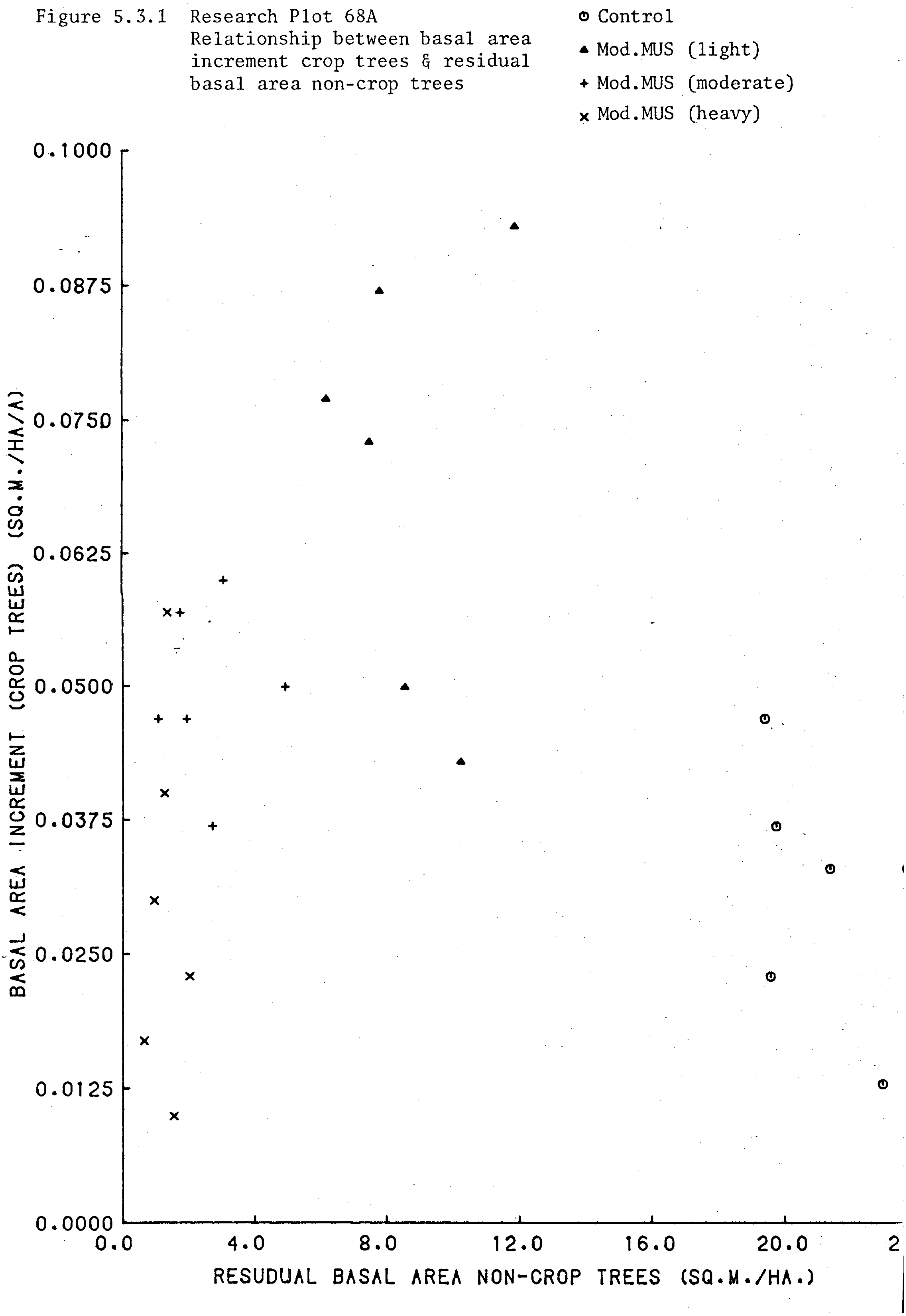


Figure 5.3.2 Research Plot 68B
Relationship between basal area increment crop trees & residual basal area non-crop trees

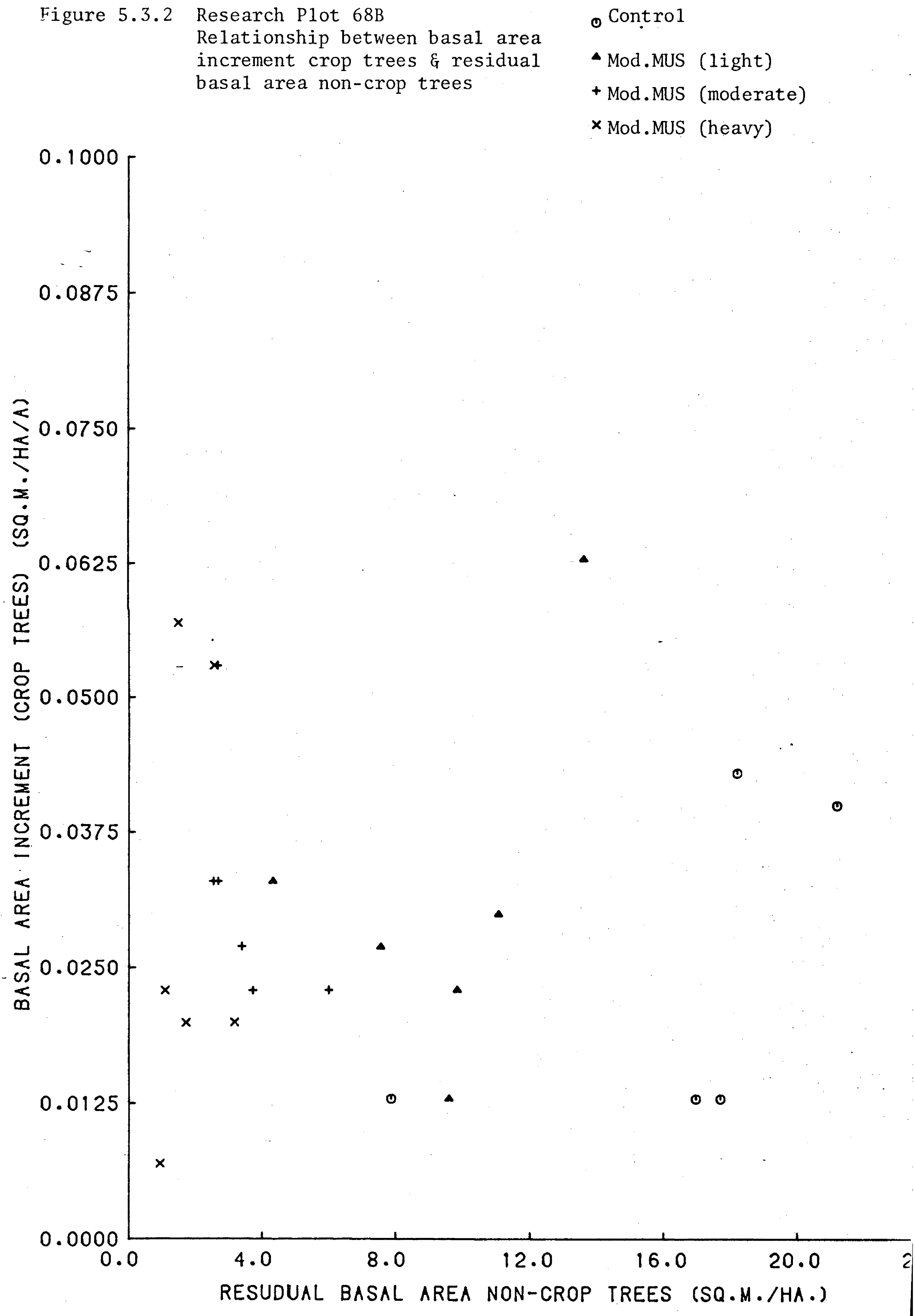


Figure 5.3.3 Research Plot 90.
Relationship between basal area increment crop trees and residual basal area non-crop trees

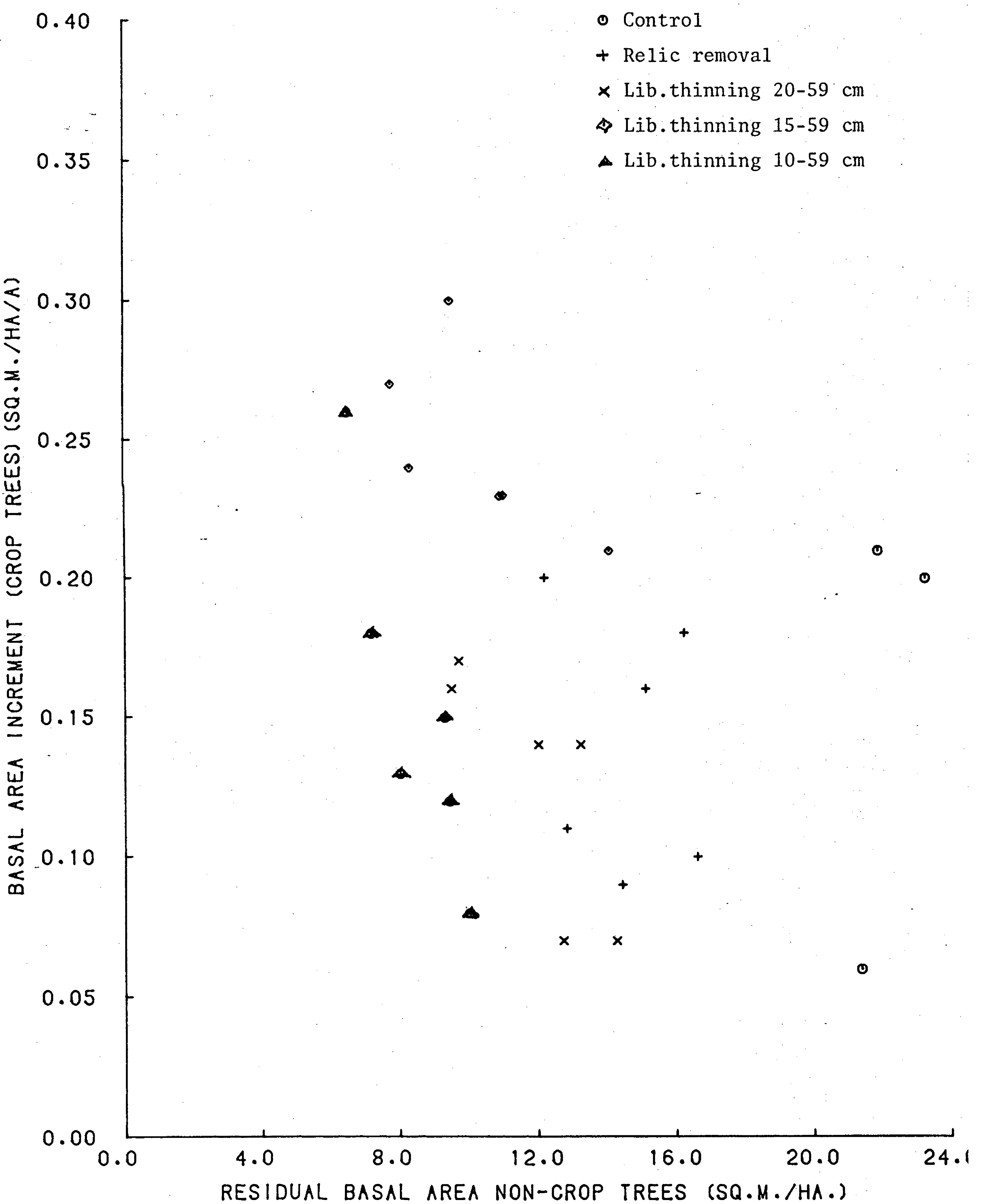
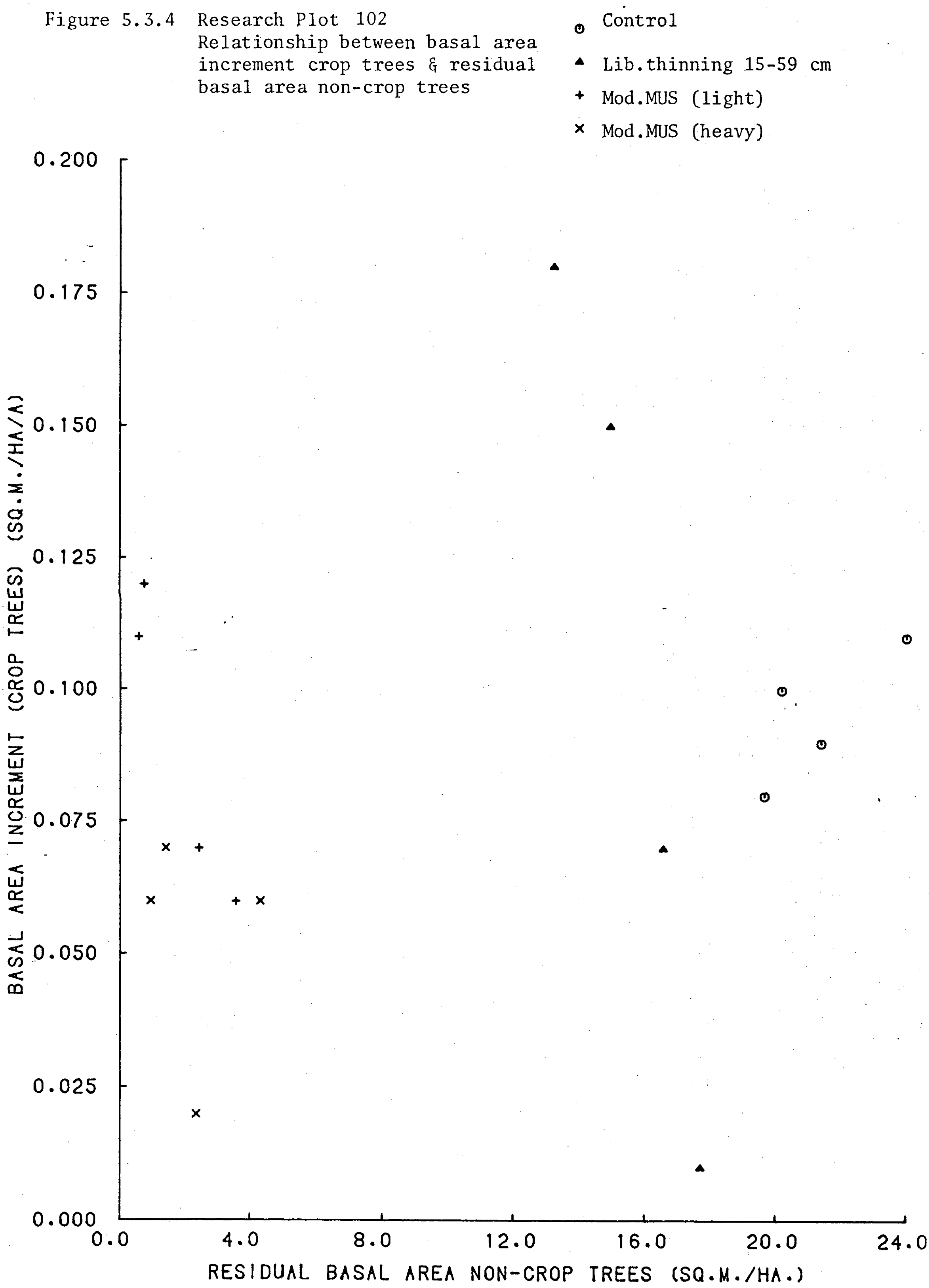


Figure 5.3.4 Research Plot 102
Relationship between basal area increment crop trees & residual basal area non-crop trees



increment with increasing residual basal area of crop trees. Further examination of these effects was carried out by regression analyses.

5.1 Estimation of Growth Functions

The GLIM (Generalised Linear Interactive Modelling) computer package Release 3 (Baker and Nelder, 1978) was utilised to estimate growth functions in a manner which enabled various hypotheses about treatment and other effects to be tested statistically.

5.1.1 Formation of models

The principal variables which seemed likely to affect basal area increment were treatment, residual basal area of crop trees and residual basal area of non-crop trees. These variables also have an important bearing on the manipulation of the forest stands. For these reasons, they were chosen as the independent variables in the formulation of the regression models. A quadratic model in residual basal area of crop trees was chosen as the basic model for all research plots because previous research suggested that increment would eventually decline as the residual basal area of crop trees increased. Thus the basic model was:

$$\Delta B_c = \delta_o + \delta_1 B_c + \delta_2 B_c^2 + \delta_3 B_{nc} \quad (5.1)$$

where ΔB_c = Periodic annual increment in gross basal area of crop trees (sq m/ha/annum)

B_c = Basal area of crop trees (sq m/ha)

B_{nc} = Basal area of non-crop trees (sq m/ha)

Treatments were represented by dummy (0,1) variables. The basic quadratic model (Equation 5.1) was further developed by the inclusion of dummy variables and interactions to enable models with -

(i) different slopes and different intercepts;

(ii) common slopes and different intercepts;

(iii) different slopes and common intercepts; and

(iv) common slopes and common intercepts

to be fitted and compared.

5.1.2 Acceptance of models

With some minor exceptions, to be reported later, a model was judged to be acceptable if -

(i) the regression coefficients were found to be jointly significantly different from zero by means of an F-test;

(ii) the individual coefficients were found to be significantly different from zero by means of t-tests;

(iii) an inspection of the scatter of residuals revealed the variance to be homogenous;

(iv) inspection of the plot of ordered residuals against normal deviates suggested that the error distribution was normal.

The design and measurement of the research plots was such that seral correlations between residuals could not have occurred and thus no formal tests were carried out for seral correlation.

If more than one model satisfied these conditions, an F-test was used to see whether the models were significantly different. If not, the simpler model was chosen.

5.2 Research Plots 90 and 102

The data from these two Research Plots were analysed first with a view to investigating the pooling of the two experiments, thereby providing a wider range of data for several treatments. These two plots provided scope for pooling because the measurements were carried out on the same basis and the species list used in both cases ~~were~~ was compatible. As noted earlier, the four subplots of RP 102 were amalgamated for this purpose to make the measurement units of both the plots comparable in area. While it could be argued that the resulting variation between measurement units in RP 102 should be less than that for RP 90 (cluster versus fixed plot), the results will show that any such difference was completely obscured by other sources of variation.

The more complex models involving treatment and/or interaction effects proved to be unacceptable in all cases because some coefficients were not significantly different from zero. Even the quadratic model had to be rejected because the coefficients of the quadratic terms were not significantly different from zero. Thus the following models were accepted as a basis for examining the pooling of these Research Plots. In each case standard errors are shown in brackets below the respective coefficients. The unadjusted multiple coefficient of determination (R^2) is also shown:

Research Plot 90

$$\Delta B_c = \underset{(0.032)}{0.092} + \underset{(0.007)}{0.042B_c} - \underset{(0.002)}{0.005B_{nc}} \qquad (5.2)$$

$$R^2 = 0.630$$

Research Plot 102

$$\Delta B_c = \underset{(0.016)}{0.062} + \underset{(0.008)}{0.017B_c} - \underset{(0.002)}{0.002B_{nc}} \tag{5.3}$$

$$R^2 = 0.332$$

Based on this model, a test for homogeneity of variance was carried out (Table 5.1).

TABLE 5.1 Test for homogeneity of variance

Research Plots 90 and 102

RP	Residual SS	d.f.	Mean square	Calc.F	Critical F @ p.95
90	0.0419	24	0.0017	1.16	2.11
102	0.0190	13	0.0015		

Thus the variances of the residuals were homogenous and the data from the two experiments were pooled. After pooling, treatment effects and interactions were further tested by fitting these models again. Again, either some of the coefficients were not significantly different from zero, rendering the model unacceptable, or the model was not significantly different from the basic model. Here, however, the quadratic term was retained because the coefficient now had a coefficient of sensible sign and magnitude which was significantly different from zero. This result no doubt reflects the wider range of the pooled data and the greater number of observations. The model was:-

$$\Delta B_c = \underset{(0.024)}{-0.010} + \underset{(0.016)}{0.106B_c} - \underset{(0.002)}{0.011B_c^{\,2}} - \underset{(0.001)}{0.003B_{nc}} \tag{5.4}$$

$$R^2 = 0.653$$

5.3 Research Plots 68A and 68B

The main difference between RP 68A and RP 68B was the use of an extended list of desirable species in RP 68B. As noted earlier (Section 4.2.2.1), the inclusion of the seven additional species contributed very little crop tree basal area. Thus this difference was ignored and the scope for pooling the two experiments was analysed along the same lines as that for RPs 90 and 102.

As before, the more complex models involving treatments and/or interactions were unacceptable in all cases because some coefficients were not significantly different from zero. The quadratic model had to be rejected also because the coefficients of the quadratic terms were not significantly different from zero. The following models were therefore accepted as a basis for pooling of these Research Plots.

Research Plot 68A

$$\Delta B_c = \underset{(0.006)}{0.040} + \underset{(0.006)}{0.019B_c} - \underset{(0.005)}{0.007B_{nc}} \qquad (5.5)$$

$$R^2 = 0.343$$

Research Plot 68B

$$\Delta B_c = \underset{(0.005)}{0.025} + \underset{(0.009)}{0.026B_c} - \underset{(0.0006)}{0.0012B_{nc}} \qquad (5.6)$$

$$R^2 = 0.267$$

A test for homogeneity of variance was then performed (Table 5.2).

TABLE 5.2 Test for homogeneity of variance
Research Plots 68A and 68B

RP	Residual SS	D.f.	Mean squares	Calc.F	Critical F p.95
68A	0.0068	21	0.0003	1.7	2.08
68B	0.0040	21	0.0001		

Thus the two experiments were pooled. After pooling, treatment effects and interactions were further tested by fitting these models again. As before, either some of the coefficients were not significantly different from zero rendering the model unacceptable, or the model was not significantly different from the basic model. In this instance, however, the coefficients of the quadratic term ~~was~~ were not significantly different from zero at the 95% probability level. Nevertheless the term had been retained because it was sensible in sign and magnitude especially relative to the results in RPs 90 and 102. The residual variance of these experiments was relatively much higher than that for RPs 90 and 102 and may be obscuring the effect of the quadratic term.

$$\Delta B_c = \underset{(0.006)}{0.024} + \underset{(0.015)}{0.043B_c} - \underset{(0.006)}{0.010B^2_c} - \underset{(0.004)}{0.0098_{nc}} \qquad (5.7)$$

$$R^2 = 0.338$$

5.4 Summary

The growth functions derived from this study suggest that the residual basal area of crop trees exerts a strong and positive influence on gross basal area increment. Increment increases rapidly as the basal area of the crop trees increases. The quadratic term in the function indicates, however, that there is a limit to this effect. Beyond this threshold value of about 5 sq m per ha for RPs 90 and 102 and 2 sq m per ha for RPs 68A and 68B, increment declines.

Gross basal area increment of crop trees is negatively related to the residual basal area of the non-crop trees.

No statistical differences between the effects of silvicultural treatments could be discerned.

CHAPTER 6

DISCUSSION OF RESULTS

The results of the previous chapter warrant careful consideration both in relation to the inferences to be drawn directly from the growth functions and to their practical implications.

6.1 Growth Functions

The nature of the estimated functions can best be grasped from a plot of the surface of the function. Figures 6.1 and 6.2 show estimated gross basal area increment plotted against the basal area of residual crop trees for various levels of basal area of residual non-crop trees based on Equations 5.4 and 5.7 respectively.

These graphs show that gross basal area increment rises to a maximum at a relatively low level of basal area of residual crop trees and declines thereafter, 5 sq m/ha for Research Plots 90 and 102 and 2 sq m/ha for Research Plots 68A and 68B respectively. The basal area of residual crop trees corresponding to this maximum increment differs somewhat in the two experiments, but this difference should not be stressed. The statistical properties of these estimates are such that the differences are probably not significant in a statistical sense, the curves being relatively flat across a wide range near the maximum. Differences between the lists of 'desirable species' in logging the respective areas may also have contributed to this minor difference.

Figure 6.1 Basal area increment function

Research Plots 90 and 102

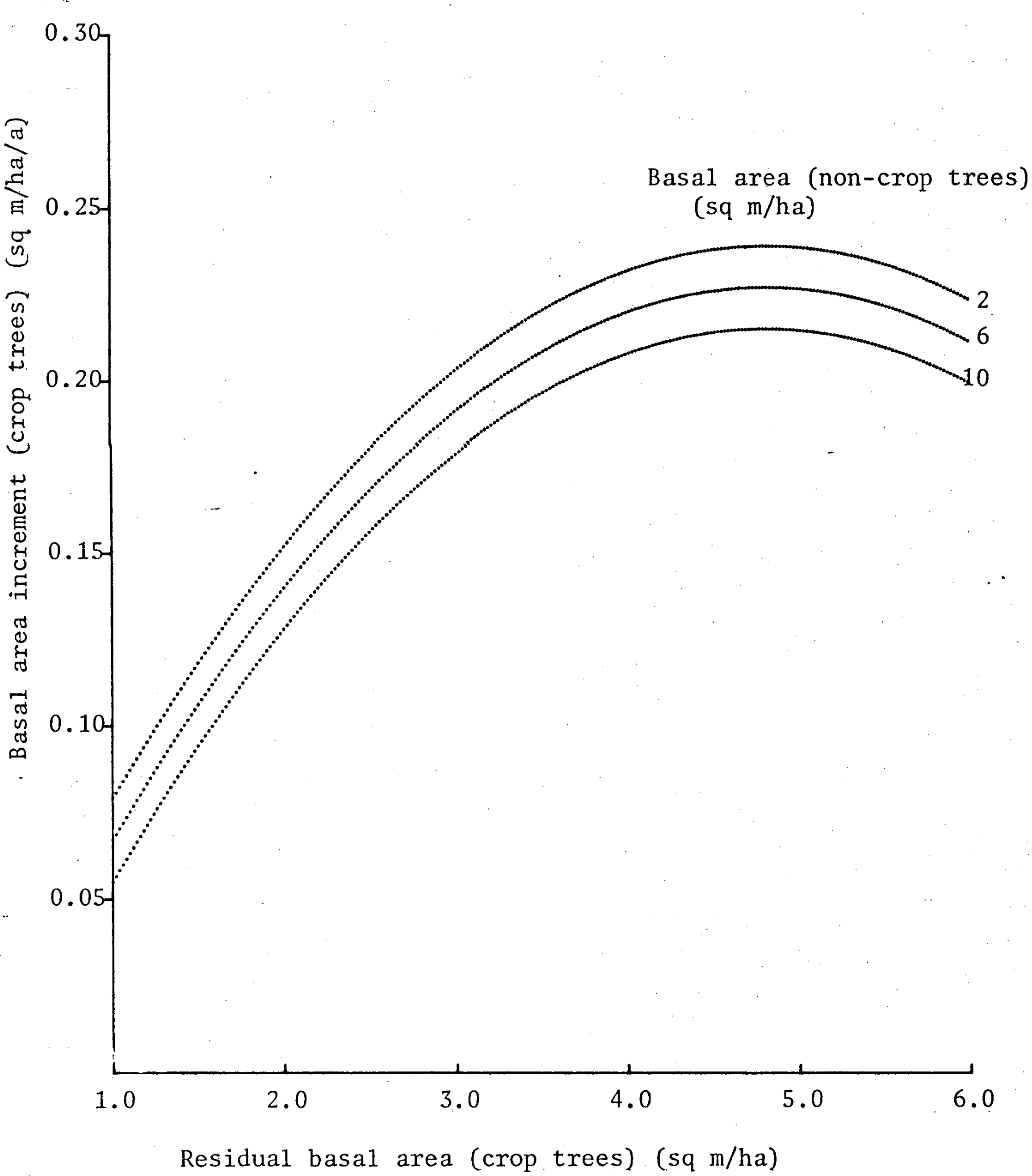
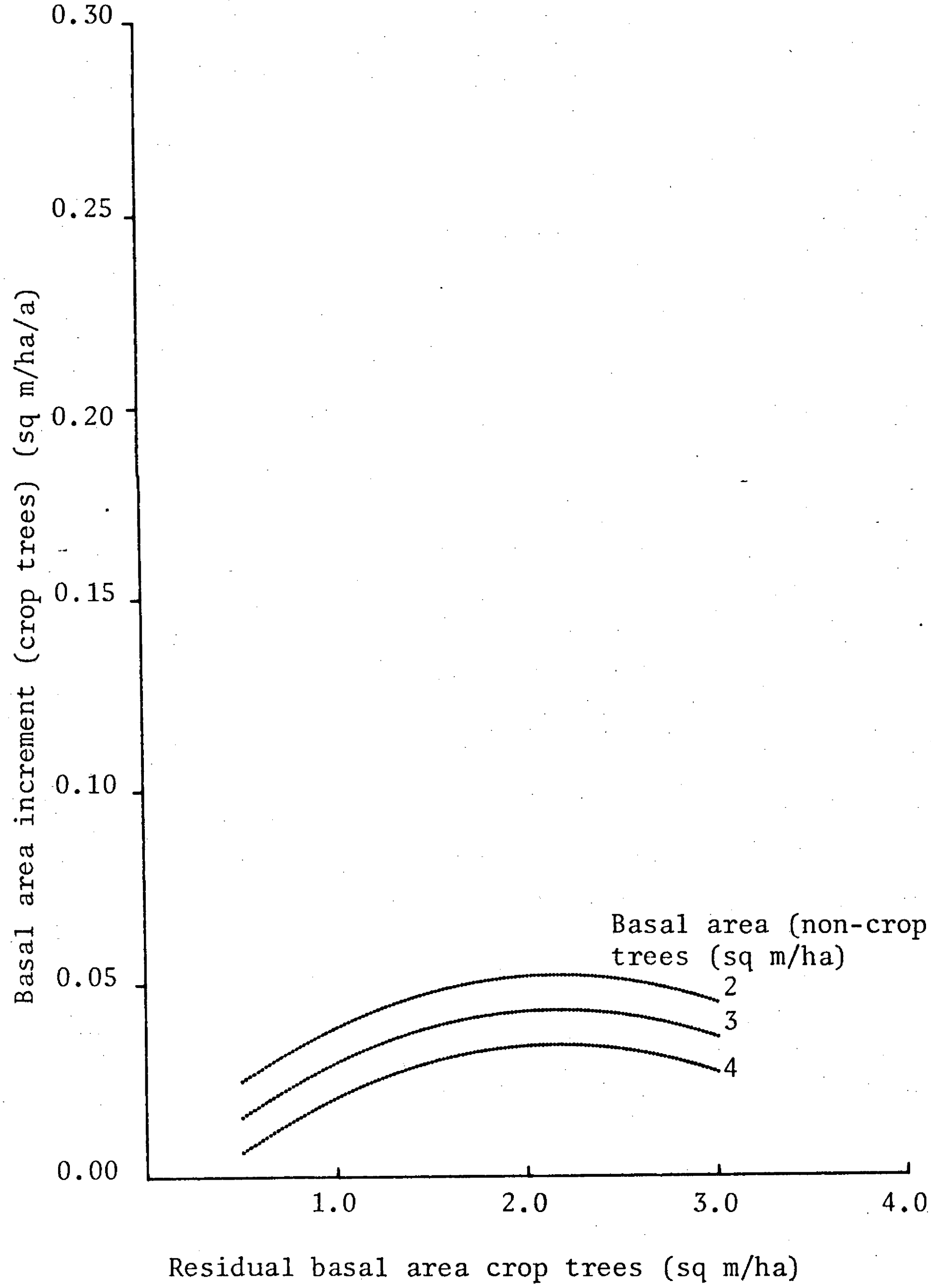


Figure 6.2 Basal area increment function

Research Plots 68A and 68B



In both experiments, the reduction in increment due to additional basal area of non-crop trees is relatively minor. The similarity between the experiments in this respect outweighs the minor differences in the magnitudes of the changes.

The conclusions have very strong implications for silvicultural practice but some words of caution need to preface them. Although it was not possible to discern statistically significant differences between silvicultural treatments, differences may still exist. Both experiments show considerable unexplained variation masking any small differences between treatments. Furthermore, the analyses to date have focussed exclusively on the pole and larger sized trees. The data need to be analysed further to examine differences in seedling and advance growth components.

6.2 Silvicultural Practice

The most obvious implication of these results is that none of the deliberate silvicultural treatments following logging have been successful in terms of promoting growth of the residual crop trees. Even if one or more of these treatments has some impact in this respect, it is clearly so small and so variable that it is of dubious value.

The more intensive Malayan Uniform System consistently resulted in extremely low levels of basal area of residual crop trees - below 0.5 sq m/ha. This is well below the level associated with maximum growth in both experiments. Moreover it is expensive, averaging 5 man-days labour per ha, and results in tremendous vine growth and invasion by fast-growing pioneer species of no commercial value. If it has a future, it could only be gauged from subsequent growth of seedling regeneration and advance growth as an essentially evenaged stand, not from the growth of residual trees.

The Liberation Thinning treatment is presently being implemented in Sarawak. By December 1980, some 3500 ha of logged forest had been treated (Lai 1981) at a cost of about 3.3 man-days labour per ha. Lai (1981) carried out a field check of operations and found that field crews were failing to treat some 50% of the potential crop trees. Given the expense, difficulty of control, and apparent ineffectiveness of the treatment in promoting growth on residual crop trees, there would seem to be little point in persisting with it.

Relic removal is probably the cheapest of the treatments because it prescribes removal of all defective trees above a certain diameter, regardless of species. Thus it is less demanding to implement than the other treatments, no botanical identification being required. It may also stimulate the seedling regeneration and advance growth although this would not be the primary objective of the treatment. Nevertheless, the evidence from these experiments is that it too fails to produce an appreciable increase in growth compared with untreated stands. However, if the removal of relics can be done concurrent with logging at little expense, it could still be a worthwhile operation.

The Forest Department should therefore enforce more strictly current regulations regarding the removal of oversized (>60 cm diameter) trees containing extractable volume by concessionaires. In areas containing high stockings of oversized trees with no extractable volume, cull felling might be carried out by the loggers. In this respect, some cull felling payment to the loggers might be considered. It must be emphasized that relic removal should not be considered a blanket prescription applicable to all areas. The need for this treatment will have to be ascertained by a prelogging sampling to determine the level of crop tree basal area.

Thus, the results of these experiments show that further treatment immediately following logging may be misplaced. The funds might be better spent on:

(i) closer control of logging operations;

(ii) treatment at some time well after logging.

6.3 Control of Logging

Closer control of logging operations seems desirable for several reasons.

It seems likely to offer the most effective and cheapest means of ensuring that the basal area of crop trees is maintained at or near the optimum level. The maximum levels noted earlier represent an upper bound on the optimum economic level. The optimum economic level probably is somewhat below this upper bound. The volume functions given in Appendix XI provide a basis for more thorough examination of the economics and need further study. Nevertheless, because of the variability of the mixed dipterocarp forest, these upper bounds probably represent a sufficient guide for present purposes.

Closer control of logging would also enable damage due to logging to be reduced. Marn and Jonkers (1980) have pointed out that damage can be reduced greatly by proper planning of roads and skidways by concessionaires and by direct supervision of logging operations.

Closer control implies a higher level of planning and the need for a prelogging sampling to obtain data for the planning of silvicultural and logging operations. Prescriptions could then be drawn up for each coupe which ensured a sufficient retention of crop trees and adequate regeneration of advance growth. This form of sampling would also indicate areas carrying low stocking of crop trees which could best be left unlogged. It would point to the most appropriate levels of crop tree basal area removal to achieve the optimum level noted earlier and therefore the diameter limits above which crop trees should be removed for specific forest areas. The prelogging sampling would also overcome the problems stemming from changes in merchantability as overseas markets change. These changes can be quite pronounced as the differences between the residual untreated stand in Research Plots 90 and 102 compared with that in Research Plots 68A and 68B testify. The post-logging inspection of logging coupes currently being implemented should be strengthened to provide a basis for enforcement of the prescriptions and the imposition of penalties.

6.4 Further Treatment

If no treatment, other than relic removal, is to be carried out at the time of logging, consideration needs to be given to treatment at later dates. While experimental data from the study indicate a considerable capacity for growth, given the appropriate level of retention of crop trees, competition will probably reduce this progressively.

Treatment 10 years after logging should be investigated to see whether it produces a sufficient response to make it economic. Experiments of this kind need to be established now so that the results are available to guide decision-making 10 years hence.

The present experiments provide some guide to the replication needed to discrimate between different treatments. The observed difference between treatments in these experiments and the true difference to be detected in future experiments enable the number of replications to be worked out in the manner described by Cochran and Cox (1957).

CHAPTER 7

CONCLUSIONS

In this study it was only possible to focus attention on the analysis of gross basal area and gross sound stem volume increments of crop trees in the residual stand. The data should be further analysed to provide estimates of other variables affecting the development of the residual stand. Further analyses should examine:-

1. Seedling regeneration and advance growth;
2. Growth rates of different size classes of the residual crop tree;
3. Logging damage to the residual stand;
4. Mortality rates.

The main conclusion to be drawn from this study is that none of the deliberate silvicultural treatments following logging has been successful in promoting growth of residual crop trees. Rather than persisting with these treatments therefore, it might be more profitable to divert funds to maintaining stricter control of the logging operation. Stricter control of logging seems to offer the most effective and cheapest way of ensuring that the basal area of crop trees is maintained at or near the optimum level. A more intensive level of planning of silvicultural and logging operations is required. Some form of pre-logging sampling is required to collect information to guide planning.

Work should therefore be initiated as soon as possible to design a sampling procedure which -

1. is easy to use and analyse in the field;
2. provides precise and unbiased estimates of basal area and other information for planning purposes at a reasonable cost.

At the same time, the present practice of post-logging inspection of logging coupes should be strengthened to provide a basis for the enforcement of silvicultural management prescriptions, where necessary by the imposition of penalties.

REFERENCES

Anon. (1964). Research Programme Forest Department Sabah.

Anon. (1972). Manual of Silviculture for use in the productive forest estate, Sabah. Sabah Forest Record No.8, Kota Kinabalu, Sabah.

Ashton, P.S. (1973). Report on research undertaken during the years 1963-1967 on the ecology of the mixed dipterocarp forest in Sarawak. MS. Botany Department, University of Aberdeen.

Baillie, I.C. (1978). Studies of site-forest relationships in the mixed dipterocarp forest of Sarawak. Report submitted to Ministry of Overseas Development, London, and Forest Department, Sarawak.

Baker, R.J. and J.A. Nelder (1978). The GLIM (Generalised Linear Interactive Modelling) System. Release 3 Manual. Numerical Algorithms Group, Oxford.

Baur, G.N. (1964). Rainforest treatment. Unasylva 18(1) No.72: 18-28.

Boerboom, J.H.A. and Wiersum, K.F. (1977). The forestry situation in east Kalimantan. A report of Department of Tropical Silviculture, Agriculture University, Wageningen (quoted by Nicholson, 1979).

Browne, F.G. (1955). Forest trees of Sarawak and Brunei. Govt. Printing Office, Kuching, Sarawak.

Burgess, P.F. (1970). An approach towards a silvicultural system for the hill forests of the Malay Peninsula. Mal.For.33(2):126-133.

Burgess, P.F. (1972). Studies on the regeneration of the hill forests of the Malay Peninsula. Mal.For. 35: 103-23.

Burgess, P.F. (1973). The impact of commercial forestry on the hill forests of the Malay Peninsula, *in* Proc. Symp. on Biol. Resources and National Development (E. Soepadmo & K.G. Singh eds.),pp.131-36, Malayan Nature Society.

Burgess, P.F. (1976). Silviculture in the hill forests of the Malay Peninsula. Forest Research Institute, Kepong. Research Pamphlet No.66.

Carmichael, J.E. and Hughes, J.H. (1976). Tropical moist forests of the Far East: Growth and yield concepts and research needs. Forestry Research Technical Report, Weyerhaeuser.

Carmichael, J.E. and Hughes, J.H. (1977). Procedure manual for dipterocarp forest growth plots. Forestry Research Technical Report, Weyerhaeuser.

Chai, D.N.P. and Udarbe, M.P. (1977). The effectiveness of current silvicultural practice in Sabah. Mal. For. 40(1): 27-35.

Cochran, W.G. and Cox, G.M. (1957). Experimental designs (2nd ed.). John Wiley & Sons, Inc.

Cockburn, P.F. (1975). Phenology of the dipterocarps in Sabah. Mal.For. 38(3): 160-170.

Dawkins, H.C. (1958). The management of natural tropical high forest with special reference to Uganda. Imp. For. Institute Paper No.34.

Department of Statistics, Malaysia (1979). Annual Statistical Bulletin 1978, published 1979.

FAO (1974). An inventory of the mixed dipterocarp forest of Sarawak 1969-1972. Volume 1 Methodology, Techniques and Results. FO:DP/MAL/72/009 Technical Report 2.

FAO (1976). Forestry and Forest Industries Development, Malaysia. Project Results, Conclusions and Recommendations. FO:DP/MAL/72/009. Terminal Report.

FAO (1978). Field instructions for the enumeration of permanent samples. MAL/76/008 (unpublished).

FAO (1979). Computer programming and processing of silvicultural research data. FO:DP/MAL/76/008 Consultancy Report.

FAO (1980). Economic data for Sarawak forestry. Draft.

FAO (1980a). Hill forest silviculture in Sarawak. Consultancy Report. Draft.

Ferguson, I.S. and Reilly, J.J. (1975). The economics of modifying eucalypt forests. Aust. For. Vol. 38(2): 134-143.

Fishwick, R.W. (1975). Forestry in Brazil. Comm.For.Rev. 54(1): 53-63.

Florence, R.G. (1976). The utilisation of tropical forests: case study of Malaysian Forestry and its relevance to Papua New Guinea. Rep. of Symp. on 'Ecological effects of increasing human activities on tropical and sub-tropical forest ecosystems'. Univ. PNG 28 Apr.-1 May 1975. Aust. UNESCO Comm. for MAB. Publ. No.3.

Florence, R.G. (1978). The silvicultural decision. For. Ecol. & Mgt.1: 293-306.

Forest Department (1970). Silviculture research programme Sarawak 1971-1975.

Forest Department (1976). Annual Report.

Forest Department (1977). Annual Report.

Forest Department (1979). Annual Report.

Forest Department (1980). Field instructions for Sarawak liberation thinning.

Fox, J.E.D. (1968). Logging damage and the influence of climber cutting prior to logging in the lowland dipterocarp forest of Sabah. Mal.For. 31(4).

Fox, J.E.D. (1972). The natural vegetation of Sabah and natural regeneration of the dipterocarp forests. Thesis submitted to University College of north Wales, Bangor.

Glori, A.V. (1979). Silvicultural practices in the Philippines. Paper to 'Symposium on Silvicultural Technologies', Tsukuba, Japan, 2-4 October, 1978. Tropical Agriculture Research Series No.12.

Griffin, M. and Caprata, M. (1977). Determination of cutting regimes under the selective management system. Paper to ASEAN Seminar on 'Tropical Rainforest Management', Kuautan, Pahang 7-10 Nov. 1977.

Huguet, L. (1979). Foreword in Nicholson (1979).

Hutchinson, I.D. (1977). Study to establish interim guidelines for silviculture and forest management of the mixed dipterocarp forest in Sarawak.

Kio, P.R.O (1976). What future for natural regeneration of tropical high forest? Comm. For. Rev. 55(4): 309-318.

Kio, P.R.O. (1980). Regeneration Methods. Paper to the Eleventh Commonwealth Forestry Conference, September 1980.

Lai, K.K. (1981). Forest Department, Kuching, Sarawak. Pers. comm.

Lee, H.S. (1971). Experimental Plan Research Plot 68. Silvicultural Research Investigation 47. Forest Department, Sarawak (unpubl.).

Lee, H.S. and Lai, K.K. (1977). A Manual of silviculture for the permanent forest estate of Sarawak. Silviculture Research Section, Forest Department, Sarawak.

Leslie, A.J. (1977). Where contradictory theory and practice co-exist. Unasylva Vol. 29, No.115.

Liew, T.C. and Wong, F.O. (1973). Density, recruitment, mortality and growth of dipterocarp seedlings in virgin and logged-over forests of Sabah. Mal. For. 36(1): 3-15.

Marn, H.M. and W. Jonkers (1980). Logging damage in tropical high forest. Paper to International Forestry Seminar 11-15 Nov. 1980, Kuala Lumpur.

Medway, L. (1972). Phenology of a tropical rainforest in Malaya. Biol. J. Linn. Soc. 4: 117-146.

Moyini, Y.Z.G. (1977). Comment on Kio's (1976) article 'What future for natural regeneration of tropical high forest?' Comm. For. Rev. 56(2): 103-4.

Ng, F.S.P. (1977). Gregarious flowering of dipterocarps in Kepong, 1976. Mal. For. 40(3): 126-137.

Nicholson, D.I. (1958). An analysis of logging damage in tropical rainforest, North Borneo. Mal. For. 21(4): 235-245.

Nicholson, D.I. (1958a). Natural regeneration of logged tropical rainforest, North Borneo. Mal. For. 21(2): 67-71.

Nicholson, D.I. (1960). Light requirements of 5 species of Dipterocarpaceae. Mal. For. 23: 344-356.

Nicholson, D.I. (1965). A review of natural regeneration in the dipterocarp forests of Sabah. Mal. For. 28(1): 4-26.

Nicholson, D.I. (1970). Forest Management Report. FO:SF/PHI 16 No.3 FAO, Rome.

Nicholson, D.I. (1979). The effects of logging and treatment on the mixed dipterocarp forests of Southeast Asia. FO:MISC/79/8.

Paijmans, K. (1976). New Guinea vegetation. Australian National University Press, Canberra.

Reyes, M.R. (1978). Possibilities of increasing the yield of tropical rainforest (dipterocarp) in the Philippines. The Phil. Lumberman Vol.24(1): 59-63.

Sasaki, S. (1979). Physiological study of Malaysian tropical tree species. Study on storage and germination of Leguminosae and Dipterocarpaceae seeds. Paper to Symp. on Silvicultural Technologies. Tropical Agriculture Research Series No.12.

Serevo, T.S. (1949). Some observations on the effects of the different methods of logging on residual stands and on natural regeneration. Phil. Journal of For. 6(4): 363-381.

Soerianegara, I. (1970). The silvicultural systems for the tropical rainforests in Indonesia. Rimba Indonesia 15(3-4).

State Planning Unit (1980). Fourth Malaysia Plan 1981-85, Sarawak Vol.1.

Synott, T.J. and Kemp, R.H. (1976). Choosing the best silvicultural system. Unasylva 28(112-3): 74-9.

Tamari, C. (1976). Phenology and seed storage trials of dipterocarps. Res. Pamph.69, FRI, Kepong, Malaysia.

Tang, H.T. (1971). Preliminary tests on the storage and collection of some *Shorea* species seeds. Mal. For. 34: 84-98.

Tang, H.T. (1980). Factors affecting regeneration methods for tropical high forests in Southeast Asia. Paper to Eleventh Commonwealth Forestry Conference, September 1980.

Thorpe, E. (1978). Report of Forest Industry Adviser. FAO: MAL/76/003.

Vincent, A.J. (1961). A Note on the growth of three Meranti hill forest species in naturally and artificially regenerated forest, Malaya. Res. Pamph. 37, FRI, Kepong, Malaya (Malaysia).

Wadsworth, F.H. (1965). Tropical regeneration practices. Proceedings of Duke University Tropical Forestry Symposium, Bulletin No.18, School of Forestry, Duke University, Durham N.C. pp.3-29.

Wadsworth, F.H. (1969). 'Posibilidades Futuras de los Bosques del Paraquay'. Documento de Trebajo No.2. Projecto PNUD/FAO/PAR/66/515, Ministero de Agricultura y Ganaderia, Ascencion. 36pp.

White, K.J. (1976). Lowland rainforest regeneration in Papua New Guinea with reference to the Vanimo subprovince. Papua New Guinea Tropical Forestry Research Note SR 32.

Whitmore, T.C. (1975). Tropical rainforests of the Far East. Clarendon Press, Oxford.

Wood, G.H.S. (1956). The dipterocarp flowering season in north Borneo, 1955. Mal For. 14(4): 193-201.

Worrell, A.C. (1956). Optimum intensity of forest land use on a regional basis. For. Sci. 2(3): 199-240.

Wyatt-Smith, J. (1954). Forest memories of the Philippines. Mal. For. 17(3): 135-143.

Wyatt-Smith, J. (1963). Manual of Malayan Silviculture for Inland Forests. Malayan Forest Record No.23.

Zulmukhshar Shaari (1979). Regeneration of hill dipterocarp forests in Peninsular Malaysia: the selective management system. Paper to Symposium on Silvicultural Technologies, Tsukuba, Japan 2-4 Oct. 1978. Tropical Agriculture Research Series No.12.

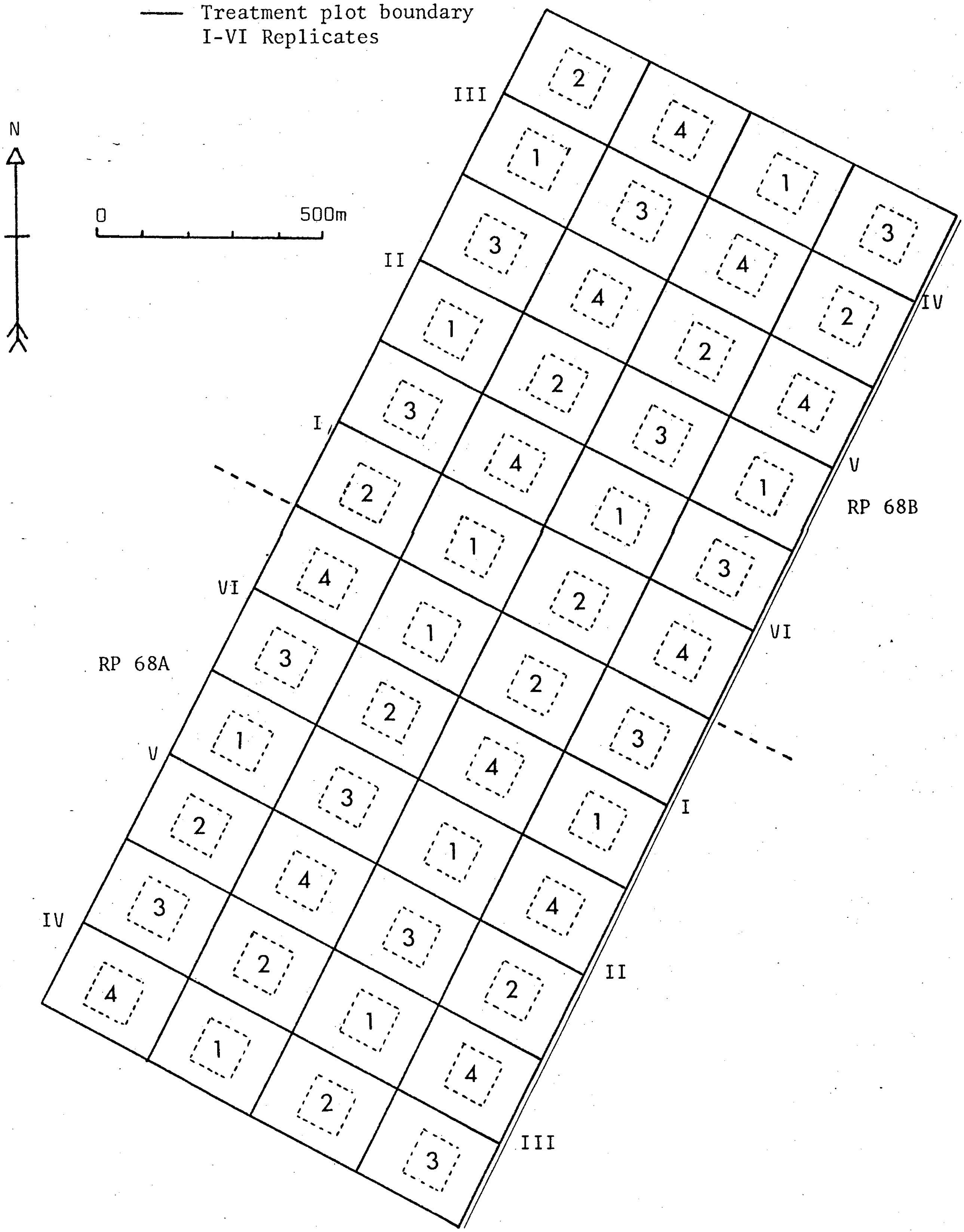
APPENDICES

APPENDIX I LAYOUT OF RESEARCH PLOT 68

Location: Niah Forest Reserve, 4th Division, Sarawak

Legend:

---- Assessment plot boundary
—— Treatment plot boundary
I-VI Replicates



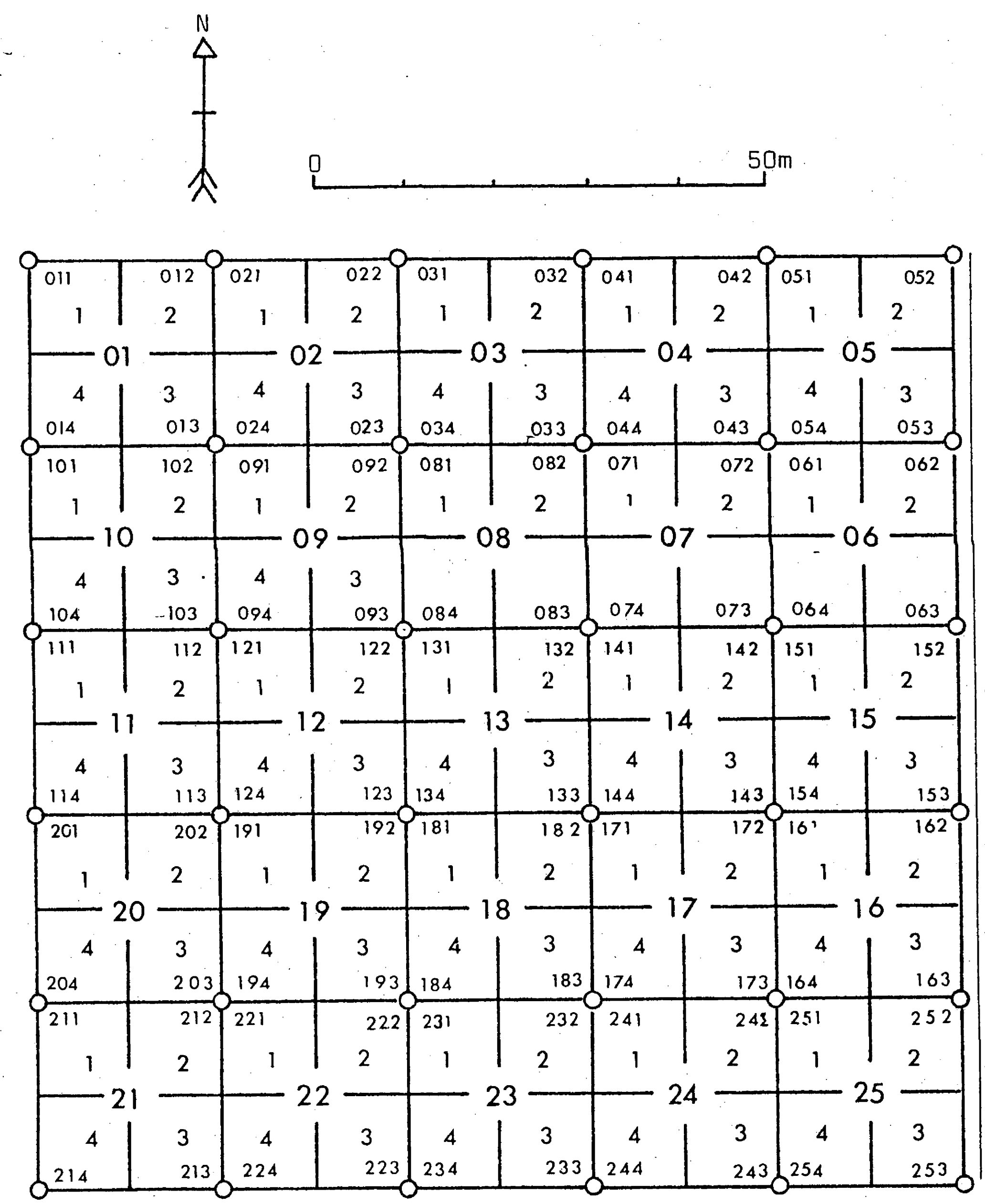
APPENDIX II DESCRIPTION OF SILVICULTURAL TREATMENTS RESEARCH PLOT 68

RP 68A

Treatment		Description
1	Control	No treatment
2	Modified Malayan Uniform System (light)	Poison girdle all unsound, damaged and badly-shaped trees over 30 cm dbh. Poison girdle all sound and well-shaped trees as follows: Dipterocarps over 60 cm dbh Undesirable species over 30 cm dbh
3	Modified Malayan Uniform System (moderate)	Poison girdle all unsound, damaged and badly-shaped trees over 10 cm dbh and all undesirable species over 10 cm dbh. Leave unpoisoned all desirable species of whatever size if sound and well-shaped.
4	Modified Malayan Uniform System (heavy)	Poison girdle all unsound, damaged and badly-shaped trees and all undesirable species over 3 m tall. Poison girdle all sound and well-shaped trees of desirable species over 30 cm dbh.
RP 68B		
1	Control	No treatment
2	Modified Malayan Uniform System (light)	Poison girdle all unsound, damaged and badly-shaped trees over 30 cm dbh. Poison girdle all sound and well-shaped trees as follows: Dipterocarps over 60 cm dbh Other desirable and acceptable species over 40 cm dbh Undesirable species over 30 cm dbh
3	Modified Malayan Uniform System (moderate)	Poison girdle all unsound, damaged and badly-shaped trees over 10 cm dbh and all undesirable and acceptable species of whatever size if sound and well-shaped.
4	Modified Malayan Uniform System (heavy)	Poison girdle all unsound, damaged and badly-shaped trees and all undesirable species over 3 m tall. Poison girdle all sound and well-shaped trees of desirable and acceptable species over 30 cm dbh.

APPENDIX III : LAYOUT OF ASSESSMENT PLOT

RESEARCH PLOTS 68 AND 90



LEGEND

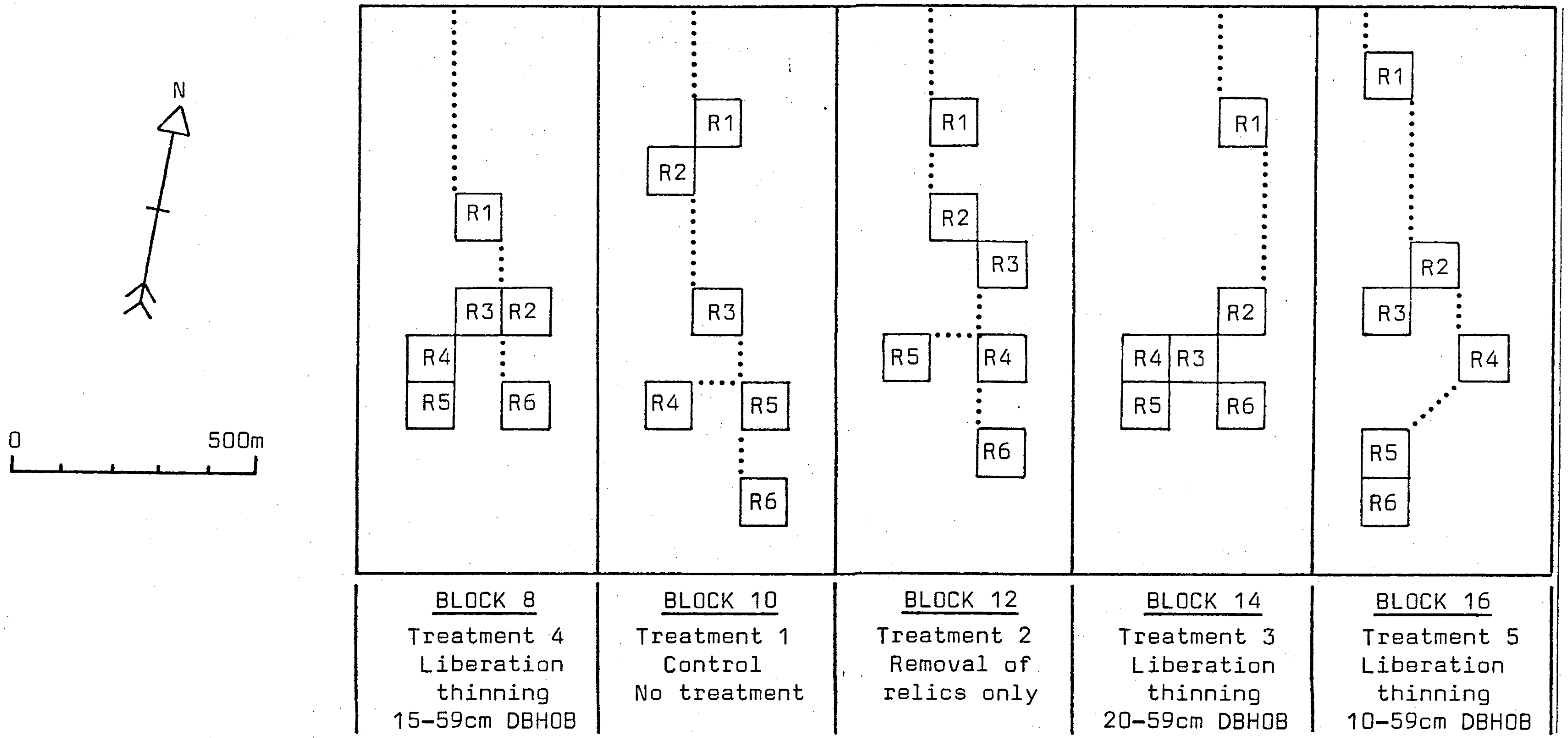
O Belian Peg

184 Quadrat Number

APPENDIX IV : LAYOUT OF RESEARCH PLOT 90

Location : Niah Forest Reserve, 4th Division Sarawak

Legend : R1 to R6 Assessment plots



APPENDIX V : FIELD PROCEDURE FOR LIBERATION THINNING (adapted from Forest Department, 1980)

To liberate a reserved tree (or potential crop tree) follow the sequence of the three steps outlined below. Before doing so, note the following three exceptions to these instructions.

(a) do not poison girdle any tree of a species protected by law,

(b) do not poison girdle any reserved tree which overtops a smaller reserved tree,

(c) do not poison girdle any relic tree of listed species (60+ cm diameter) which, although it may overtop a reserved tree, stands on a landing, or within 30 m of the edge of a landing.

The three steps for liberating a reserved tree are as follows.

Step One: POISON GIRDLE ALL TREES (except other reserved trees) WHICH OVERTOP A RESERVED TREE.

Step two: POISON GIRDLE ALL TREES (except other reserved trees) WHICH ARE SEEN TO BE COMPETING WITH THE RESERVED TREE.

Competing trees generally stand at a similar crown level to a reserved tree. Do not consider to be a 'competitor' any tree which is overtopped or dominated by a reserved tree.

You may poison girdle trees smaller than 10 cm dbhob whenever you find them, .

(a) competing with the crown of a reserved tree,

(b) growing in such a way that their stem and/or branches press or rub against the trunk of the reserved tree.

Step three: POISON GIRDLE ALL TREES (except other reserved trees) WHICH ARE FOUND, BY MEASUREMENT, TO STAND CLOSER TO A RESERVED TREE THAN THE DISTANCE SHOWN IN THE DISTANCE TABLE. Do not apply the distance table to trees smaller than 10 cm dbhob.

BE SYSTEMATIC. DO NOT HURRY.

MAKE SURE YOU DO NOT POISON ANY TREE GOOD ENOUGH TO BE RESERVED.

APPENDIX V (contd)

THE DISTANCE TABLE

(Table of Minimum Distance permitted from a reserved tree to any neighbouring tree which is NOT a reserved tree)(After Wadsworth, 1969)

(Metres)

Reserved tree	Diameter bhob (cm)	Neighbouring tree (not a reserved tree) - diameter dbhob (cm): 10-12	13-17	18-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-59	60+
Reserved tree	10-12	2.5	3.0	3.5	4.0	4.0	4.5	5.0	5.5	6.0	6.0	6.5	Poison-girdle all trees 60+ cm dbhob, except listed species standing on landings or within 30 m of the edge of landings.
	13-17	3.0	3.5	4.0	4.0	4.5	5.0	5.5	6.0	6.0	6.5	7.0	
	18-22	3.5	4.0	4.0	4.5	5.0	5.5	6.0	6.0	6.5	7.0	7.5	
	23-27	4.0	4.0	4.5	5.0	5.5	6.0	6.0	6.5	7.0	7.5	7.5	
	28-32	4.0	4.5	5.0	5.5	6.0	6.0	6.5	7.0	7.5	7.5	8.0	
	33-37	4.5	5.0	5.5	6.0	6.0	6.5	7.0	7.5	7.5	8.0	8.5	
	38-42	5.0	5.5	6.0	6.0	6.5	7.0	7.5	7.5	8.0	8.5	8.5	
	43-47	5.5	6.0	6.0	6.5	7.0	7.5	7.5	8.0	8.5	8.5	9.0	
	48-52	6.0	6.0	6.5	7.0	7.5	7.5	8.0	8.5	8.5	9.0	9.5	
	53-57	6.0	6.5	7.0	7.5	7.5	8.0	8.5	8.5	9.0	9.5	9.5	
	58-59	6.5	7.0	7.5	7.5	8.0	8.5	8.5	9.0	9.5	9.5	10.0	

Notes: (a) In the forest, distances obtained from this table should be measured in the horizontal plans.
(b) Do not apply this table to trees smaller than 10 cm diameter bhob.
(c) Do not apply this table to other reserved trees.

APPENDIX VI SAMPLE OF FIELDCARD

A

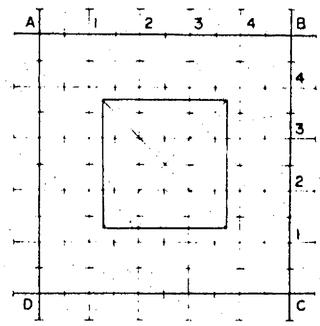
FIELDCARD FOR FORESTRY RESEARCH

UNDP/FAO, MAL/76/008 1980

TOTAL NUMBER OF RECORDS (LINE ENTRIES) IN THIS QUADRAT

MAXIMUM VALUE RECORDED FOR CONSECUTIVE STEM NUMBER:

SKETCH-MAP OF QUADRAT



(SCALE: 0.5 cm ≙ ONE METRE)

FILE INFORMATION

RESEARCH PLOT No.	TYPE SILV TRMT	YEAR OF ENUMN	DECIMAL DATE	SAMPLE SIZE
			–	1

Date: . . . . . / . . . . . /19 . . . .

NAMES OF STAFF MEMBERS

LINE ENTRIES: TREES 10.0 CMS + DBHOB.

6. QUADRAT STOCKED? (Yes, 1 : No, 2)

7. FOREST CLASS OF QUADRAT

10. TREATMENT BLOCK (REPLICATION No.)

12. ASSESSMENT PLOT NUMBER

14. QUADRAT NUMBER

LOCALITY: . . . . .FR/PF.

REMARKS: . . . .

PAGE: 1, 2

STEM IDENTITY								STEM DESCRIPTION																				
	SIC	BOTANICAL						SILV.		DIAMETER		HEIGHT		CROWN		TREE		INJURY				DECAY						
			GROUPS	BOTANICAL CODE No.																		POSITION						
CONSECUTIVE STEM NUMBER	STEM IDENTITY CLASS	VERNACULAR NAME	WOOD QUAL.	FAMILY	GENERA	DIVISION		DIAGNOSTIC SAMPLE	SILVICULTURAL TREATMENT	DIAMETER BHOB MILLIMETRES	UPPER TRUNK DIAMETER OVERBARK MILLIMETRES	TRUNK HEIGHT IN METRES	TOTAL TREE HEIGHT IN METRES	CROWN ILLUMINATION	CROWN FORM	LEAN	STABILITY	ROOTS	BUTT-LOWER	UPPER TRUNK	CROWN	ROOTS	BUTT-LOWER	UPPER TRUNK	CROWN	LOG GRADE	WOODY CLIMBERS	
17	19		22-24	25-30				31	32	34-37	38-41	42-45		46-47		48-49		50 – 53				54 – 57				58	59	
00	xxx		0	xx	00	xx		0	xx	0 0 0 0	x x x x	00	xx	0	x	0	x	0	x	0	x	0	x	0	x	0	x	

RECORD CLOSED FOR THE FOLLOWING CONSECUTIVE STEM NUMBERS — No. YEAR

No. YEAR

NOTE: MAKE NO ENTRIES IN COLUMNS 23 & 24

S Tan 1980

APPENDIX VI (cont)

7-9 TABLE OF FOREST CLASSES "IMPEDED" (ADD 10) BOUNDARIES ON THE GROUND	DOM/OVERTOPPED BY LARGE TREES GOOD SITE	IN THE AIR ABOVE THE QUADRAT LARGE TREES POOR SITE	SMALL TREES GOOD SITE	SMALL TREES POOR SITE	EXPOSED TO LIGHT GOOD SITE	EXPOSED TO LIGHT POOR SITE
50% QUADRAT AREA IS						
1 FOREST CLASSES - GROUP I UNPRODUCTIVE	(1-100% OF QUADRAT AREA)				(100% AREA)	
10 SWAMP, NATURAL		102		104		106
12 WATER IMPOUNDED BY LOGGING		122		124		126
14 WATERCOURSE		142		144		146
16 STERILE SITE		162		164		166
	(VARIABLE CANOPY OPENING)				(100% AREA)	
18 OPEN SPACE, NATURAL, LONG-TERM		182		184		186
FOREST CLASSES - GROUP II TEMPORARY OPENINGS						
2 BARE SOIL	(1-100% OF QUADRAT AREA)				(100% AREA)	
20 FULLY EXPOSED TO LIGHT					205	206
22 FULLY EXPOSED MARGINALLY INFL BY SM TR					225	226
24 FULLY EXPOSED MARGINALLY INFL BY LG TR					245	246
26 BARE SOIL OVERTOPPED	261	262	263	264		
3 TEMPORARY OPEN SPACE	(VARIABLE CANOPY OPENINGS)				(100% AREA)	
30 FULLY EXPOSED TO LIGHT					305	306
32 FULLY EXPOSED MARGINALLY INFL BY SM TR					325	326
34 FULLY EXPOSED MARGINALLY INFL BY LG TR					345	346
35 TEMPORARY OPEN SPACE OVERTOPPED	361	362	363	364		
FOREST CLASSES - GROUP III STANDING FOREST						
IMMATURE FOREST						
REGENERATING FOREST RESIDUAL PREDOMINANTLY SMALL TREES						
4 DISTURBED BY LOGGING	(<50% OF QUADRAT AREA)				(100% AREA)	
40 PREDOMINANTLY INTOLERANT SPECIES SAPLINGS	401	402	403	404	405	406
42 PREDOMINANTLY INTOLERANT SPECIES SM. TR.	421	422			425	426
44 PREDOMINANTLY TOLERANT SPECIES SAPLINGS	441	442	443	444	445	446
46 PREDOMINANTLY TOLERANT SPECIES SM. TR.	461	462			465	466
5 NOT DISTURBED BY LOGGING	(< 50% OF QUADRAT AREA)				(100% AREA)	
50 PREDOMINANTLY INTOLERANT SPECIES SAPLINGS	501	502	503	504	505	506
52 PREDOMINANTLY INTOLERANT SPECIES SM TR	521	522			525	526
54 PREDOMINANTLY TOLERANT SPECIES SAPLINGS	541	542	543	544	545	546
56 PREDOMINANTLY TOLERANT SPECIES SM. TREES	561	562			565	566
6 MOSTLY PALMS	(< 50% OF QUADRAT AREA)				(100% AREA)	
60 DISTURBED BY LOGGING	601	602	603	604	605	606
62 NOT DISTURBED BY LOGGING	621	622	623	624	625	626
7 RESIDUAL PREDOMINANTLY LARGE TREES	(> 50% OF QUADRAT AREA)				(100% AREA)	
70 DISTURBED BY LOGGING	701	702			705	706
72 NOT DISTURBED BY LOGGING	721	722			725	726
8 MATURE FOREST	(<50% OF QUADRAT AREA)				(100% AREA)	
80 NOT DISTURBED BY LOGGING	801	802	803	804	805	806

INTOLERANT TREE SPECIES (LIGHT-DEMANDING PIONEER OR SECONDARY SPECIES).
BENUAH, ENTIMAU, KELAMPAYAN, LEGAI, MARKUBONG, MATA IKAN, MENARONG, MENYAM, SABA BUBU, SABAL [illegible]

19-21. STEM IDENTITY CLASSES	XX1 COMPL TRUNK	XX2 BROKEN STEM	XX3 BROKEN STUMP	XX4 CUT STUMP	XX9 NOT FOUND
1 TREE SPECIES STEMS 10.0+ CMS. DBHOB					
11 TREE ALIVE, STANDING	111	112	113	114	119
12 TREE ALIVE, FALLEN	121	122	123	124	129
13 TREE DEAD, STANDING	131	132	133	134	139
14 TREE DEAD, FALLEN	141	142	143	144	
4 MATURE PALMS (TOTAL HEIGHT 2.0+ METRES)					
41 PALM ALIVE, STANDING	411	412	413	414	419
42 PALM ALIVE FALLEN	421	422	423		429
43 PALM DEAD, STANDING	431	432	433	434	439
44 PALM DEAD, FALLEN	441	442	443		
7 CROWNED PARASITES ON DEAD STEMS (CODE NUMBERS DESCRIBE HOST STEM)					
A PARASITE ALIVE					
71 HOST TREE DEAD STANDING	711	712	713	714	719
72 HOST TREE DEAD FALLEN	721	722	723		729
73 HOST PALM STANDING	731	732	733	734	739
74 HOST PALM FALLEN	741	742	743		749
B PARASITE DEAD					
75 HOST DEAD STANDING	751	752	753	754	759
76 HOST DEAD FALLEN	761	762	763		
8 CROWNED PARASITES STANDING ALONE (CODE NUMBERS DESCRIBE THE PARASITE ITSELF)					
81 PARASITE ALIVE STANDING	811	812	813	814	819
82 PARASITE ALIVE FALLEN	821	822	823		829
83 PARASITE DEAD STANDING	831	832	833	834	839
84 PARASITE DEAD FALLEN	841	842	843		

31. DIAGNOSTIC SAMPLE

A. LEADING DESIRABLE SELECTED IN QUADRAT

TREES NOT SELECTED AS LEADING DESIRABLE	0
CROWN ILLUMN TREE LD EMERGT OR "FULL OVERHEAD LIGHT"	1
CROWN ILLUMN TREE LD SOME OVERHEAD LIGHT	2
CROWN ILLUMN TREE LD MOSTLY SIDELIGHT	3
CROWN ILLUMN TREE LD NO DIRECT LIGHT	4
B WHEN NO TREE LD, WRITE FOR ALL LINE ENTRIES	
LEADING DESIRABLE IS A SAPLING [illegible] EROCARP	5
LEADING DESIRABLE IS A SAPLING L[illegible]ED SPECIES NON-DIPTEROCARP	6
LEADING DESIRABLE IS A SEEDLING DIPTEROCARP	7
LEADING DESIRABLE IS A SEEDLING LISTED SPECIES NON-DIPTEROCARP	8
THE QUADRAT CONTAINS NO LEADING DESIRABLE	9

SKETCH-MAP OF QUADRAT

COMPASS ORIENTATION OF QUADRAT
CORNER A DUE WEST - DUE NORTH
CORNER B DUE NORTH — DUE EAST
CORNER C DUE EAST — DUE SOUTH
CORNER D DUE SOUTH — DUE WEST
THE CORNERS, ABCD, OF ALL QUADRATS IN AN ASSESSMENT PLOT TO BE ORIENTED IN THE SAME DIRECTION
FOR FIRST ENUMERATIONS, SHOW RESERVED TREES, CUT STUMPS, ALL TREES 10.0+ CMS DBHOB, LIVING OR WHICH DIED AFTER TREATMENT, TRACTOR TRACKS, WATERCOURSES, FOREST CLASSES & FOREST CLASS BOUNDARIES
FOR LATER ENUMERATIONS, SHOW NEW RECRUITS AND CORRECTIONS ONLY

32-33 SILVICULTURAL TREATMENT

STEM DEAD BEFORE TREATMENT	10
RESERVED TREE	11
STEM FULLY - GIRDLED	12
STEM PARTLY - GIRDLED	13
STEM NOT TOUCHED BY TREATMENT	14
FELLED AS PART OF SILVICULTURAL TRMT	15

46. CROWN ILLUMINATION

EMERGENT	1
FULL OVERHEAD LIGHT	2
SOME OVERHEAD LIGHT	3
MOSTLY SIDELIGHT	4
NO DIRECT LIGHT	5

47. CROWN FORM

COMPLETE CIRCLE	1
IRREGULAR CIRCLE	2
HALF - CIRCLE	3
LESS THAN HALF-CIRCLE	4
ONLY A FEW BRANCHES	5
MAINLY COPPICE	6
ALIVE, BUT NO CROWN	7

48. STEM LEAN

ERECT, LEAN LESS THAN 15 DEGREES	1
LEAN, NATURAL INFLUENCES	2
LEAN, NATURAL CAUSES	3
LEAN, DUE TO LOGGING	4
LEAN, DUE TO SILVICULTURAL TREATMENT	5

49. STEM STABILITY

STEM APPEARS COMPLETELY STABLE	1
POSSIBLE FALL WITHIN FIVE YEARS	2
CERTAIN FALL WITHIN FIVE YEARS	3

50-53 TREE INJURY

NO INJURY EVIDENT	1
DUE TO STORM	2
DUE TO FLORA AND FAUNA	3
LOGGING - HEAVY MACHINERY	4
LOGGING - FELLING ONLY	5
LOGGING - MACHINERY + FELLING	6
CONSEQUENCE OF SILVICULTURAL TREATMENT	7

54-57. TREE DECAY

NO SIGNS OF DECAY	1
PRESENCE OF DECAY SUSPECTED	2
DECAY IS EVIDENT	3

58. LOG GRADE

COMMERCIAL NOW (4+ METRES TO 45 CMS)	1
COMMERCIAL IN FUTURE (4+ METRES LONG)	2
NO LOG STEM DEFORMED	3
NO LOG STEM DAMAGED	4
NO LOG STEM DECAYED	5

59. WOODY CLIMBERS

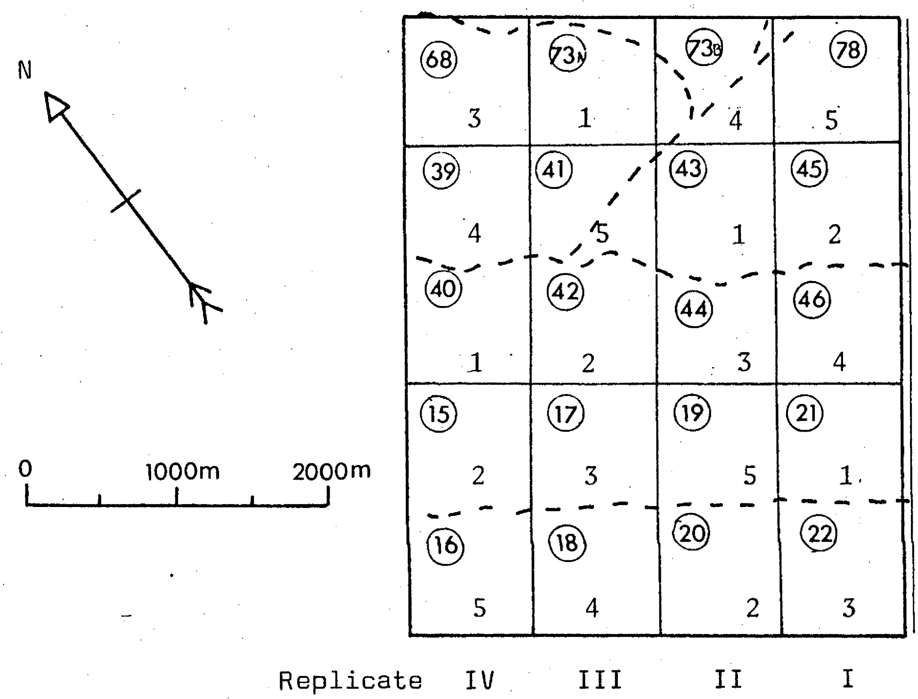
NONE EVIDENT ON TREE	1
RECENTLY CUT NONE REMAIN ALIVE	2
RECENTLY CUT HARMLESS SPECIES ALIVE	3
HARMLESS CLIMBERS ON TRUNK	4
HARMLESS CLIMBERS ON CROWN	5
HARMLESS CLIMBERS ON TRUNK & CROWN	6
HARMFUL CLIMBERS ON TRUNK	7
HARMFUL CLIMBERS ON CROWN	8
HARMFUL CLIMBERS ON TRUNK & CROWN	9

UNIT AREAS

ASSESSMENT PLOT	1.00 OR 0.25	HA
QUADRAT	0.01	HA
SAPLING SUBPLOT	0.0025	HA
SEEDLING SUBPLOT	0.000625	HA

APPENDIX VII LAYOUT OF RESEARCH PLOT 102

Location: Sawai Protected Forest, 4th Division, Sarawak



LEGEND

– – – Logging Road

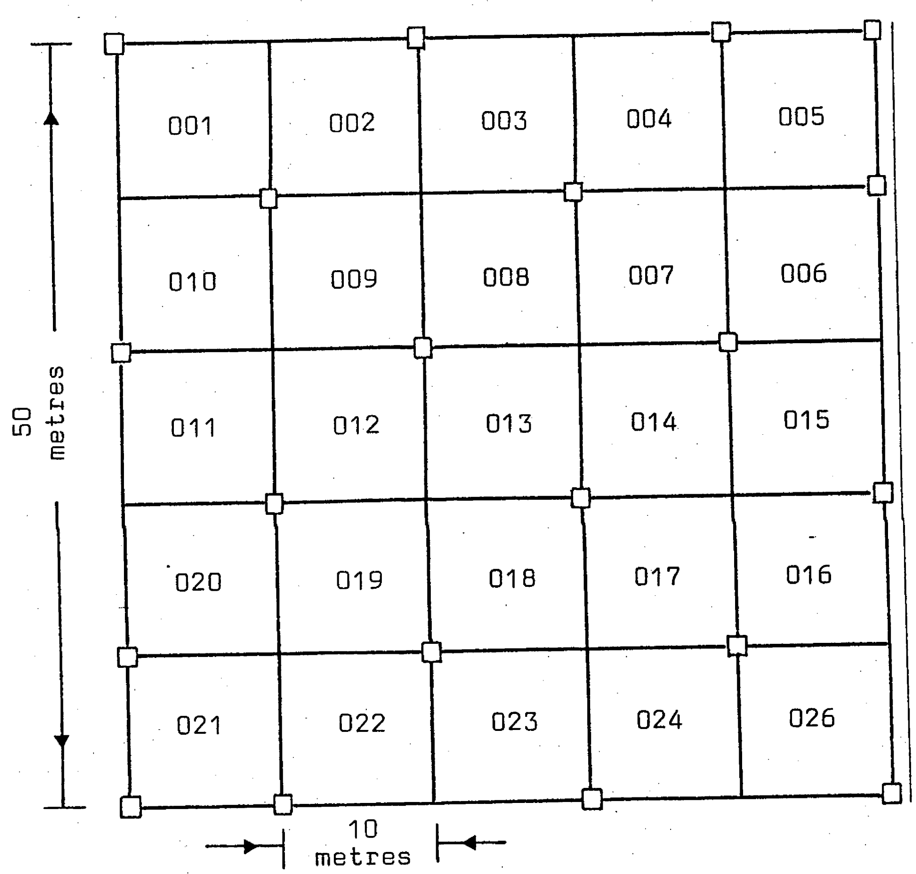
(17) Cutting Block No.

Treatment:

1 (1) Control (no treatment)
2 (2) Liberation thinning 15-59 cm dbhob
3 Liberation thinning 10-59 cm dbhob
4 (3) Modified Malayan Uniform System (light)
5 (4) Modified Malayan Uniform System

The figures in brackets are treatment reference that is used in the text for this Research Plot.

APPENDIX VIII : LAYOUT OF ASSESSMENT PLOT
RESEARCH PLOT 102



LEGEND

001 - QUADRAT NUMBER
□ - BELIAN PEG

APPENDIX IX : GROSS BASAL AREA (sq m/ha)

(a) Research Plot 68A

Treatment	Rep.	Residual b.a. (sq m/ha) Crop tr.	Non-crop	Total	Δb.a. (sq m/ha/a	Basal area original stand
1	1	1.04	19.76	20.80	0.037	29.29
	2	0.12	22.98	23.10	0.013	32.40
	3	0.41	19.43	19.84	0.047	29.80
	4	0.90	23.73	24.63	0.033	28.00
	5	0.72	19.57	20.29	0.023	32.32
	6	0.34	21.40	21.74	0.033	35.95
	Mean	0.59	21.15	21.73	0.031	31.29
2	1	0.43	6.18	6.61	0.077	28.63
	2	1.13	7.81	8.94	0.087	34.11
	3	2.27	11.90	14.17	0.093	29.68
	4	0.63	8.57	9.20	0.050	32.61
	5	0.78	7.49	8.27	0.073	32.03
	6	1.22	10.25	11.47	0.043	28.89
	Mean	1.08	8.70	9.78	0.071	30.99
3	1	0.20	1.76	1.96	0.057	34.95
	2	2.32	4.93	7.25	0.050	34.14
	3	0.47	1.09	1.56	0.047	37.71
	4	1.22	3.09	4.31	0.060	31.71
	5	0.92	1.95	2.87	0.047	32.21
	6	0.51	2.72	3.23	0.037	34.49
	Mean	0.94	2.59	3.53	0.050	33.27
4	1	0.11	0.66	0.77	0.017	23.96
	2	0.12	2.03	2.15	0.023	33.64
	3	0.22	1.28	1.50	0.040	28.63
	4	0.36	1.37	1.73	0.057	29.83
	5	0.16	1.56	1.72	0.010	29.54
	6	0.29	0.96	1.25	0.030	30.43
	Mean	0.21	1.31	1.52	0.030	29.34

APPENDIX IX (cont.)

(b) Research Plot 68B

Treatment	Rep.	Residual b.a.(sq m/ha) Crop tr.	Non-crop	Total	Δ b.a. (sq m/ha/a)	Basal area original stand
1	1	0.19	7.87	8.06	0.013	28.63
	2	0.41	17.71	18.12	0.013	37.67
	3	0.75	18.22	18.97	0.043	32.76
	4	1.71	25.43	27.14	0.017	33.28
	5	1.07	21.20	22.27	0.040	26.79
	6	0.83	16.97	17.80	0.013	27.75
	Mean	0.83	17.90	18.73	0.023	31.15
2	1	0.13	4.31	4.44	0.033	29.36
	2	0.44	9.83	10.27	0.023	37.03
	3	1.34	13.65	14.99	0.063	28.52
	4	0.33	7.55	7.88	0.027	36.39
	5	1.02	11.06	12.08	0.030	33.96
	6	0.23	9.59	9.82	0.013	33.66
	Mean	0.58	9.33	9.91	0.032	33.15
3	1	0.64	2.67	3.31	0.033	33.19
	2	0.59	2.53	3.12	0.033	31.34
	3	0.46	3.38	3.84	0.027	29.45
	4	0.88	5.97	6.85	0.023	33.04
	5	0.77	2.65	2.42	0.053	33.92
	6	0.22	3.71	3.93	0.023	29.32
	Mean	0.59	3.49	4.08	0.032	31.71
4	1	0.26	1.48	1.74	0.057	33.66
	2	0.12	1.09	1.21	0.023	28.81
	3	0.13	0.94	1.07	0.007	29.38
	4	0.15	3.16	3.31	0.020	38.30
	5	0.52	2.55	3.07	0.053	36.19
	6	0.23	1.71	1.94	0.020	36.70
	Mean	0.24	1.82	2.06	0.030	33.84

APPENDIX IX (cont.)

(c) Research Plot 90

Treatment	Rep.	Residual b.a.(sq m/ha) Crop	Non-crop	Total	Δ b.a. (sq m/ha/a)	Basal area original stand
1	2	3.94	23.26	27.20	0.20	29.67
	3	5.32	21.89	27.21	0.21	30.07
	6	3.23	21.39	24.62	0.06	28.78
	Mean	4.16	22.18	26.34	0.16	29.50
2	1	2.34	16.62	18.96	0.10	34.75
	2	3.82	12.21	16.03	0.20	26.23
	3	1.38	14.44	15.82	0.09	28.10
	4	4.35	16.26	20.61	0.18	36.02
	5	1.28	12.84	14.12	0.11	24.45
	6	3.40	15.14	18.54	0.16	29.73
	Mean	2.76	14.59	17.33	0.14	29.88
3	1	2.04	13.25	15.29	0.14	25.01
	2	2.14	12.03	14.17	0.14	27.21
	3	2.61	9.74	12.35	0.17	27.73
	4	1.34	14.28	15.62	0.07	30.80
	5	4.36	9.53	13.89	0.16	29.99
	6	1.24	12.73	13.97	0.07	27.70
	Mean	2.28	11.93	14.22	0.13	28.07
4	1	3.67	11.03	14.70	0.23	29.89
	2	4.30	7.79	12.09	0.27	32.31
	3	3.01	14.08	17.09	0.21	36.50
	4	3.50	9.52	13.02	0.30	33.49
	5	3.65	10.93	14.58	0.23	42.76
	6	3.97	8.34	12.31	0.24	31.17
	Mean	3.68	10.28	13.97	0.25	34.35
5	1	2.73	8.03	10.76	0.13	26.09
	2	2.75	9.47	12.22	0.12	25.22
	3	1.97	9.33	11.30	0.15	25.65
	4	5.15	6.52	11.67	0.26	35.67
	5	2.18	10.04	12.22	0.08	27.37
	6	3.83	7.18	11.00	0.18	30.88
	Mean	3.10	8.43	11.53	0.15	28.48

APPENDIX IX (cont)

(d) Research Plot 102

Treatment	Rep.	Residual b.a. (sq m/ha)			Δ b.a. (sq m/ha/a)	Basal area original stand
		Crop	Non-crop	Total		
1	1	6.54	21.42	27.96	0.09	33.91
	2	3.01	19.68	22.69	0.08	26.81
	3	4.65	20.21	24.86	0.10	28.13
	4	6.13	24.03	30.16	0.11	32.62
	Mean	5.08	21.34	26.42	0.10	30.37
2	1	2.89	13.24	16.13	0.18	34.91
	2	1.67	16.58	18.25	0.07	32.51
	3	0.16	17.71	17.87	0.01	30.29
	4	3.16	14.97	18.13	0.15	32.07
	Mean	1.97	15.63	17.60	0.10	32.45
3	1	1.47	0.57	2.04	0.11	34.27
	2	2.18	0.76	2.94	0.12	28.57
	3	0.99	3.56	4.55	0.06	28.88
	4	1.59	2.44	4.03	0.07	27.76
	Mean	1.56	1.83	3.39	0.09	29.88
4	1	0.86	0.94	1.80	0.06	28.04
	2	1.05	1.41	2.46	0.07	30.61
	3	1.22	4.30	5.52	0.06	22.58
	4	0.36	2.36	2.72	0.02	26.23
	Mean	0.87	1.69	3.13	0.05	26.87

APPENDIX X : GROSS SOUND STEM VOLUME (cu m/ha)

(a) Research Plot 68A

Treatment	Rep.	Residual volume			Δ Vol. (cu m/ha/a)
		Crop	Non-crop	Total	
1	1	10.7	176.9	187.6	0.39
	2	0.6	205.8	206.4	0.10
	3	3.5	163.0	166.5	0.42
	4	7.2	194.2	201.4	0.16
	5	6.4	172.1	178.5	0.10
	6	2.9	207.3	210.2	0.19
	Mean	5.2	186.6	191.8	0.23
2	1	3.0	27.4	30.4	0.44
	2	10.4	44.5	54.9	0.91
	3	20.8	72.2	93.0	1.02
	4	3.7	36.0	39.7	0.23
	5	6.6	38.9	45.5	0.61
	6	10.7	48.0	58.7	0.24
	Mean	9.2	44.5	53.7	0.58
3	1	1.0	6.2	7.2	0.29
	2	23.9	41.3	65.2	0.41
	3	4.0	5.4	9.4	0.27
	4	12.7	20.8	33.5	0.57
	5	9.0	11.9	20.9	0.36
	6	3.2	20.1	23.3	0.44
	Mean	9.0	17.6	26.6	0.39
4	1	0.7	2.7	3.4	0.00
	2	0.9	14.6	15.5	0.13
	3	1.6	7.8	9.4	0.27
	4	0.9	7.2	8.1	0.18
	5	0.7	9.5	10.2	0.12
	6	1.9	5.3	7.2	0.19
	Mean	1.1	7.9	9.0	0.15

APPENDIX X (cont)

(b) Research Plot 68B

Treatment	Rep.	Residual volume			Δ Vol. (cu m/ha/a)
		Crop	Non-crop	Total	
1	1	1.76	72.2	74.0	0.00
	2	4.15	162.9	168.1	0.00
	3	6.91	162.5	169.4	0.30
	4	16.98	223.0	240.0	0.07
	5	10.44	182.7	193.1	0.26
	6	7.82	133.4	141.2	0.10
	Mean	8.01	156.3	164.3	0.12
2	1	0.37	16.4	16.8	0.03
	2	4.03	50.1	54.1	0.09
	3	11.08	76.6	87.7	0.42
	4	2.38	38.2	40.6	0.40
	5	8.17	61.8	70.0	0.15
	6	1.89	50.9	52.8	0.00
	Mean	4.65	49.0	53.7	0.18
3	1	6.26	17.8	24.1	0.29
	2	5.94	14.8	20.7	0.33
	3	3.65	17.0	20.7	0.02
	4	9.12	45.7	54.8	0.25
	5	7.45	18.2	25.7	0.49
	6	1.66	24.2	25.9	0.16
	Mean	5.68	23.0	28.7	0.26
4	1	1.34	6.6	7.9	0.34
	2	0.00	2.6	2.6	0.00
	3	0.75	3.4	4.2	0.00
	4	0.75	22.9	23.7	0.07
	5	2.76	16.9	19.7	0.28
	6	1.39	10.9	12.3	0.11
	Mean	1.17	10.6	11.7	0.13

APPENDIX X (cont)

(c) Research Plot 90

Treatment	Rep.	Residual volume			Δ Vol. (cu m/ha/a)
		Crop	Non-crop	Total	
1	2	35.6	196.3	232.0	2.50
	3	53.3	175.2	228.5	2.35
	6	34.5	175.2	209.8	0.73
	Mean	41.1	182.2	223.4	1.86
2	1	22.0	136.5	158.6	1.03
	2	37.0	91.4	128.4	2.10
	3	13.2	111.5	124.7	1.04
	4	38.1	126.7	164.8	2.07
	5	9.9	95.8	105.7	1.26
	6	30.5	110.9	141.4	1.45
	Mean	25.1	112.1	137.2	1.49
3	1	20.9	112.2	133.1	1.61
	2	21.1	74.9	96.0	1.83
	3	26.4	58.8	85.2	1.93
	4	14.1	113.5	127.6	0.81
	5	44.5	63.0	107.5	1.80
	6	12.7	98.8	111.5	0.69
	Mean	23.3	86.9	110.1	1.45
4	1	34.7	67.5	102.2	2.76
	2	40.9	45.9	86.8	3.15
	3	28.7	100.1	128.8	2.52
	4	31.4	52.5	83.9	3.42
	5	33.7	63.2	96.9	3.13
	6	38.8	46.5	85.3	2.82
	Mean	34.7	62.6	97.3	2.97
5	1	26.1	58.0	84.1	1.47
	2	25.5	75.0	100.5	1.38
	3	17.9	80.8	98.7	1.67
	4	49.2	37.0	86.2	3.33
	5	19.5	70.5	89.9	0.80
	6	35.7	47.8	83.5	2.04
	Mean	29.0	61.5	90.5	1.78

APPENDIX X (cont)

(d) Research Plot 102

Treatment	Rep.	Residual volume			Δ Vol. (cu m/ha/a)
		Crop	Non-crop	Total	
1	1	68.13	168.18	236.31	0.80
	2	30.10	148.01	178.11	0.70
	3	43.21	170.13	213.34	1.19
	4	60.77	202.22	262.99	1.03
	Mean	50.55	172.14	222.69	0.93
2	1	26.77	80.92	107.69	2.12
	2	16.18	107.57	123.75	0.72
	3	1.57	150.63	152.20	0.04
	4	31.27	111.94	143.21	1.66
	Mean	18.95	112.77	131.71	1.37
3	1	12.89	0.65	13.54	0.88
	2	20.23	3.91	24.14	1.02
	3	8.56	37.31	45.87	0.88
	4	13.85	22.41	36.26	0.85
	Mean	13.88	16.07	29.95	0.91
4	1	7.74	6.74	14.48	0.99
	2	9.58	10.62	20.20	0.79
	3	11.53	40.66	52.19	0.67
	4	2.60	21.09	23.69	0.11
	Mean	7.86	19.78	27.64	0.64

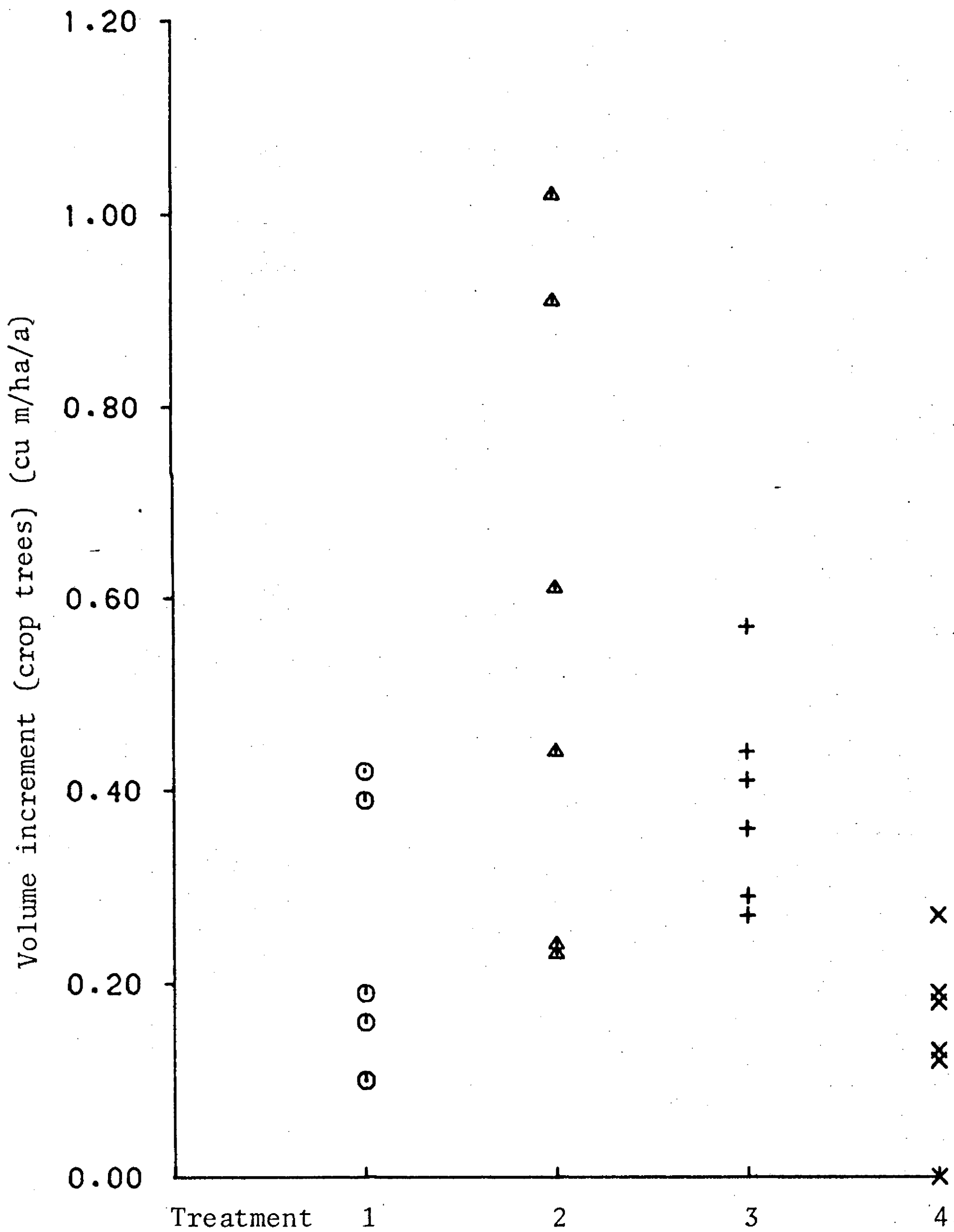
APPENDIX XI GROSS SOUND STEM VOLUME INCREMENTS AND ESTIMATION OF VOLUME INCREMENT FUNCTIONS

INDEX

APPENDIX XI

(a) (i) Research Plot 68A

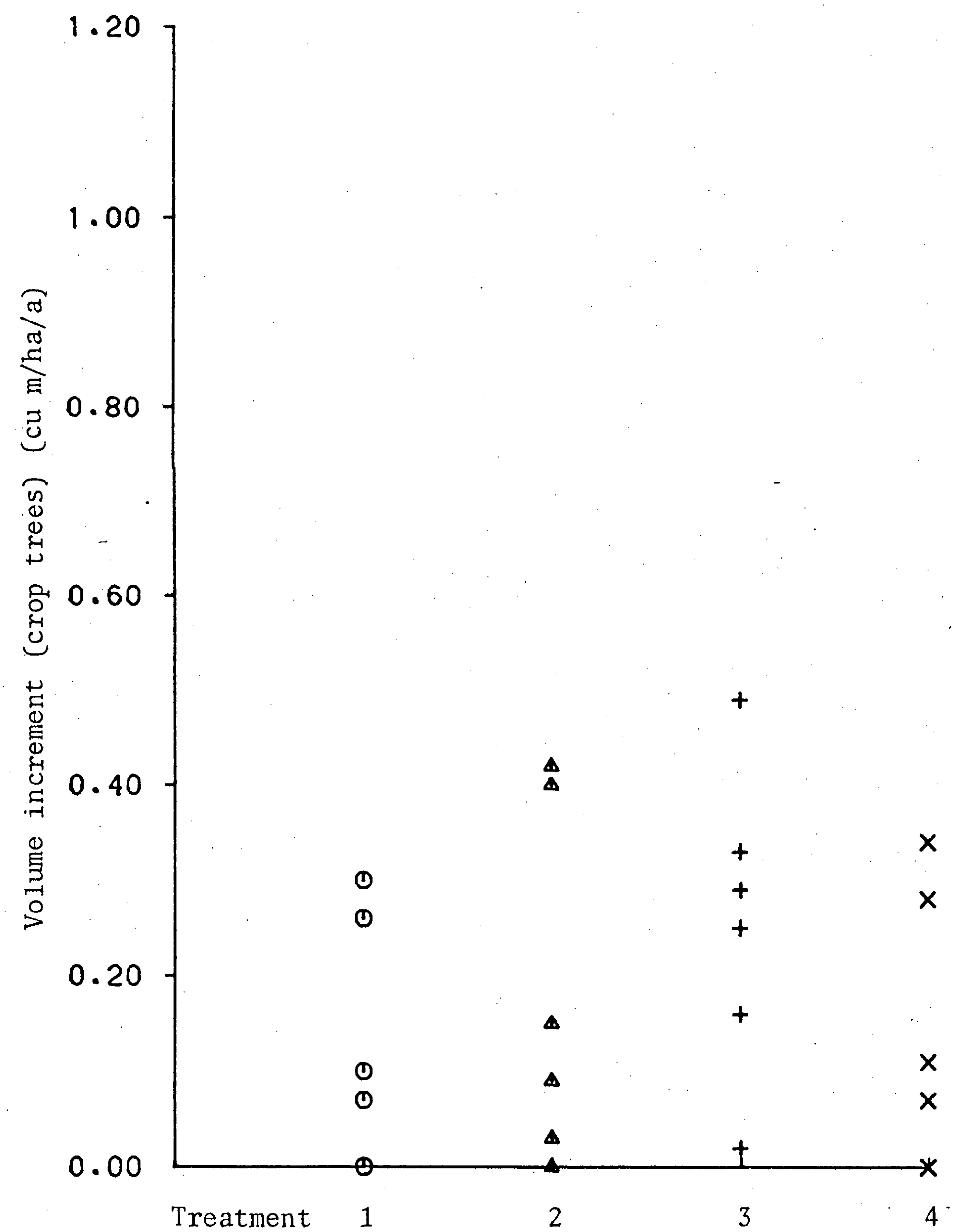
Volume increment by treatment



APPENDIX XI

(a) (ii) Research Plot 68B

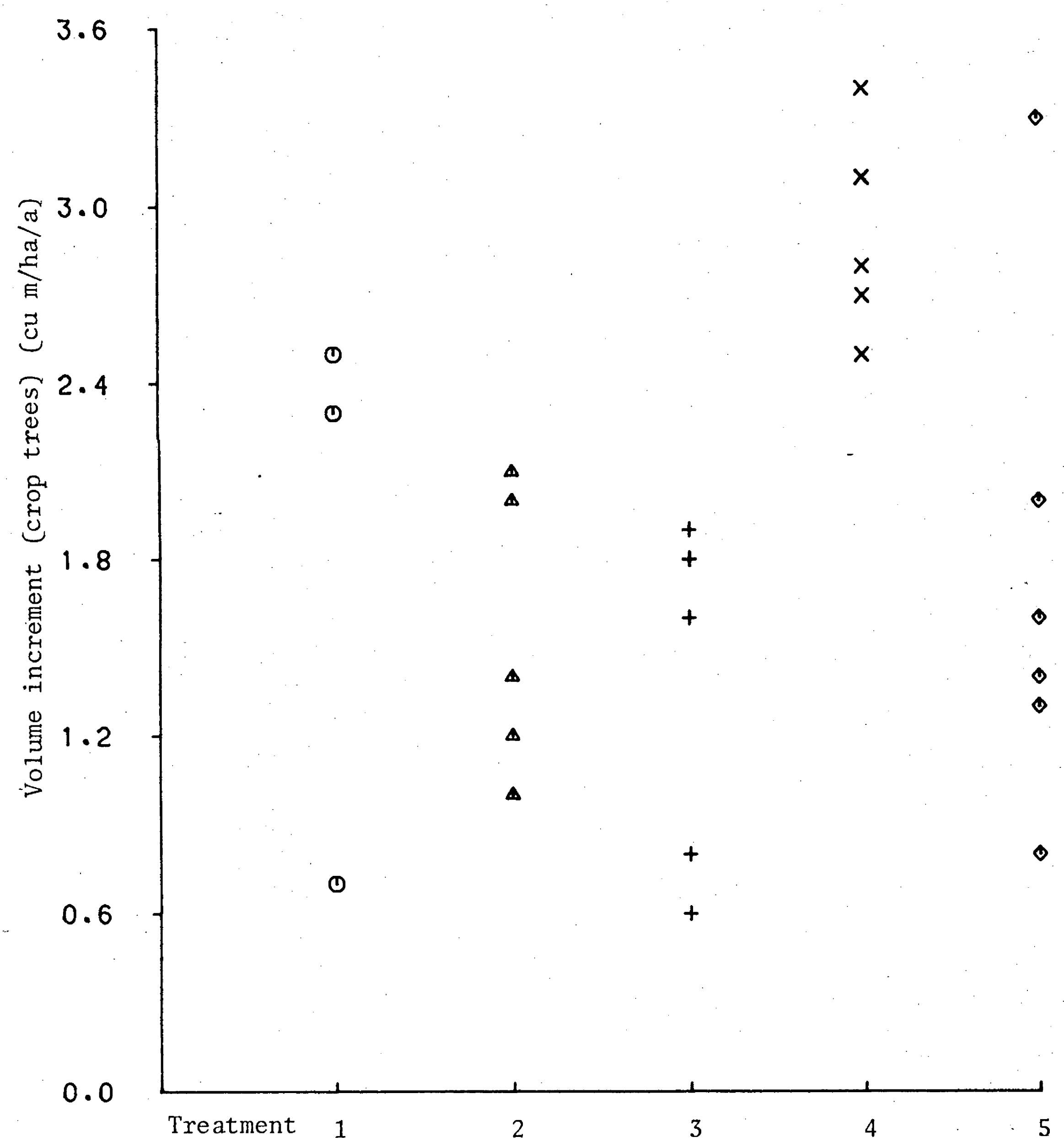
Volume increment by treatment



APPENDIX XI

(a) (iii) Research Plot 90

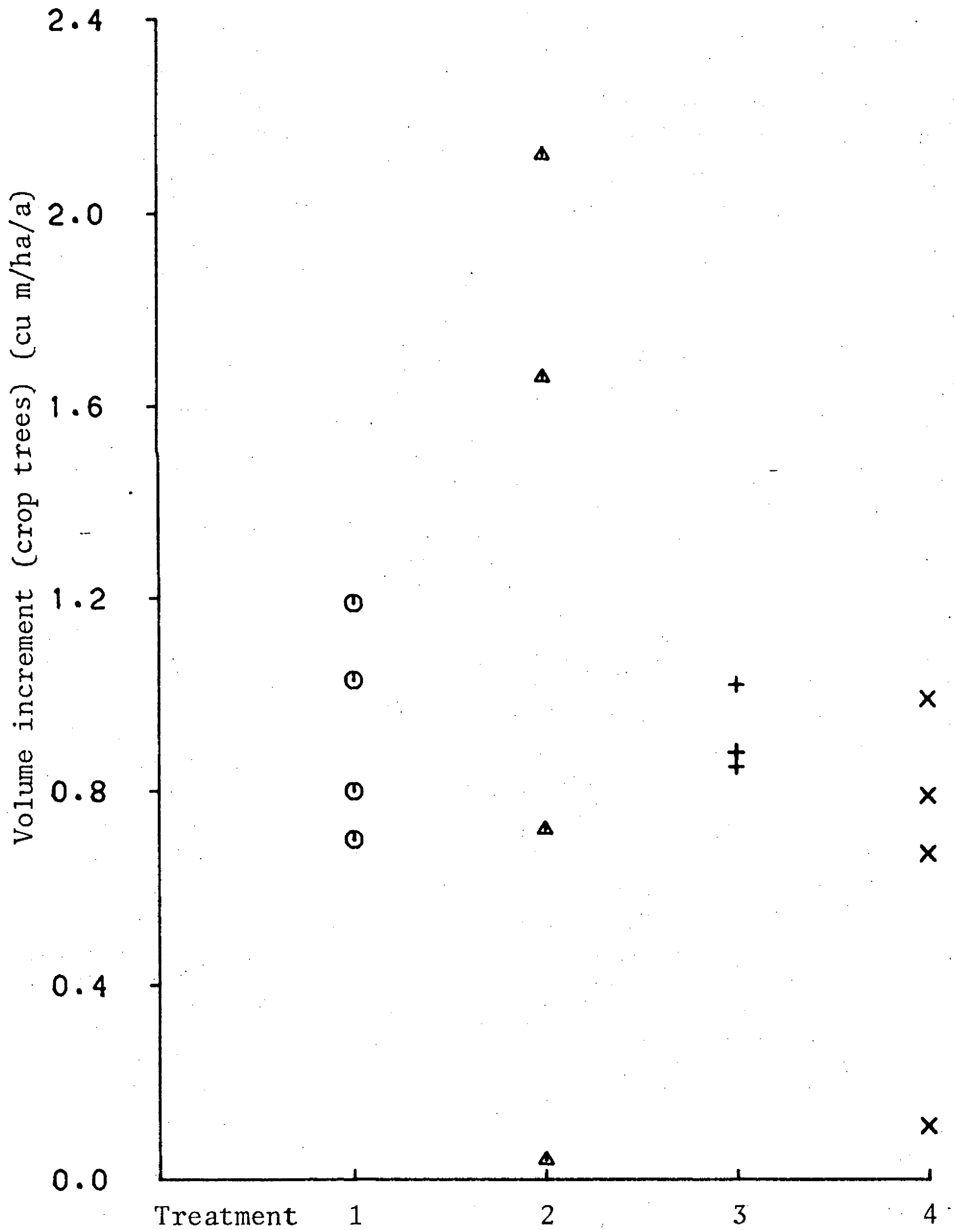
Volume increment by treatment



APPENDIX XI

(a) (iv) Research Plot 102

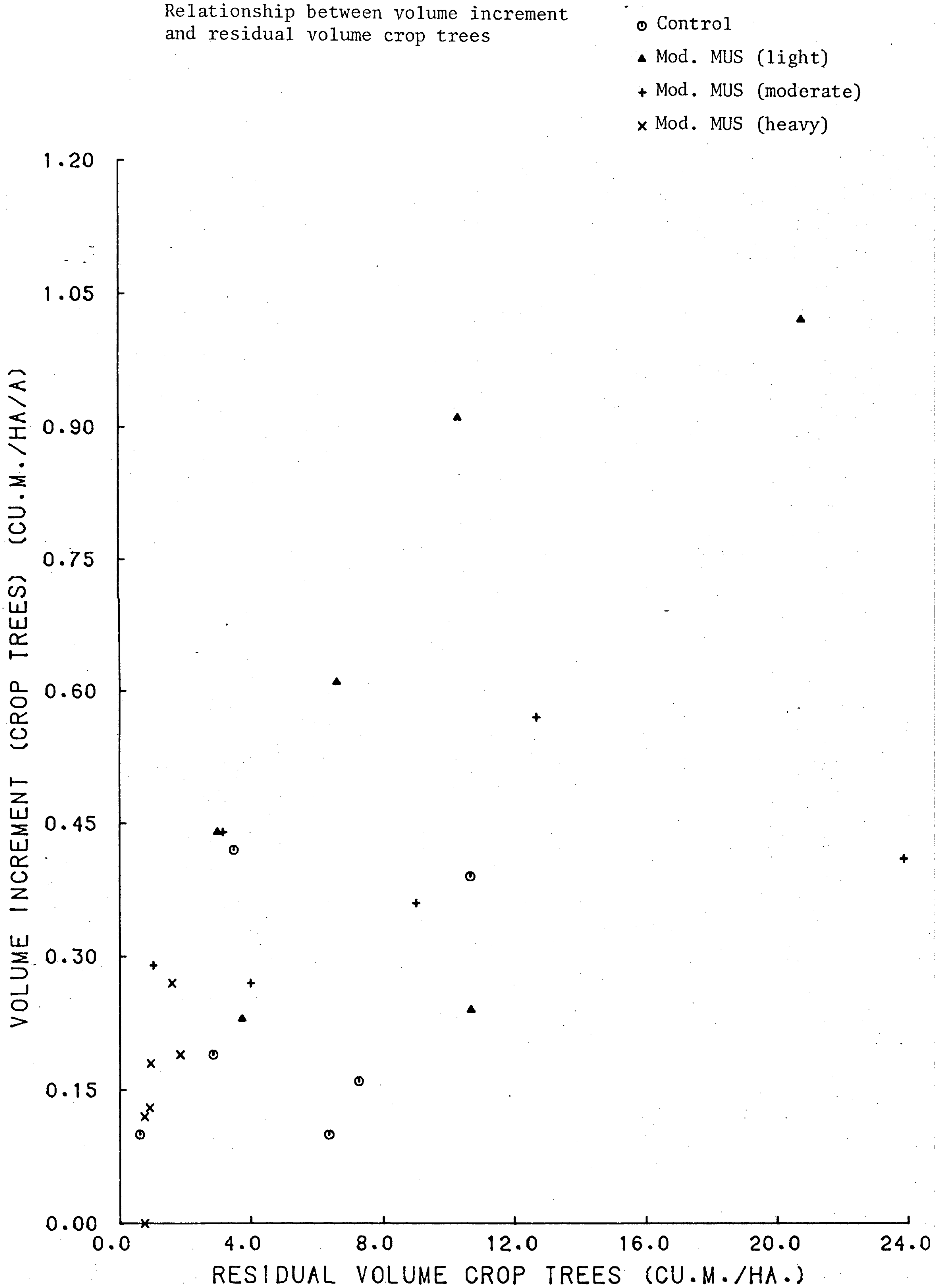
Volume increment by treatment



APPENDIX XI

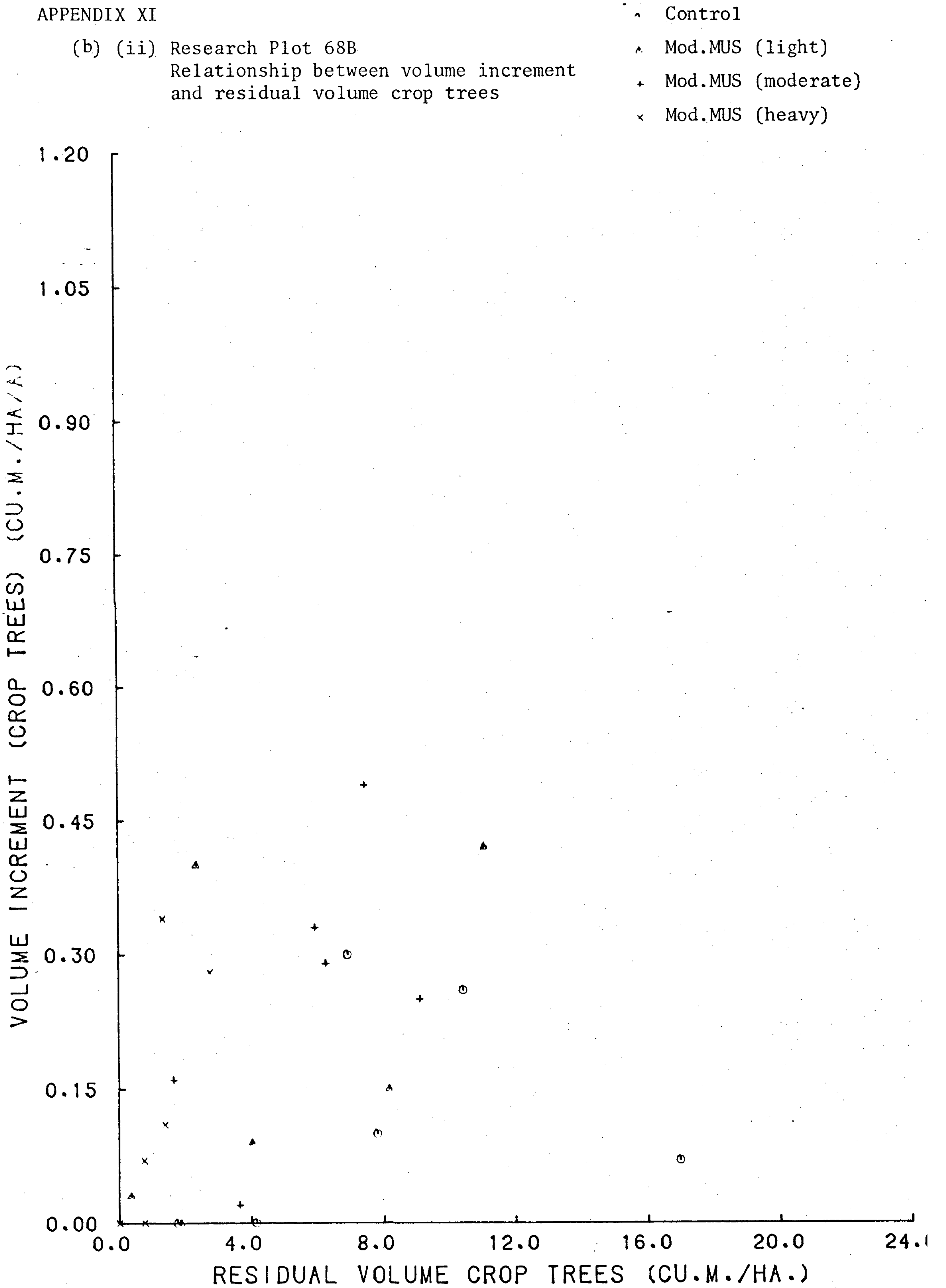
(b) (i) Research Plot 68A

Relationship between volume increment and residual volume crop trees



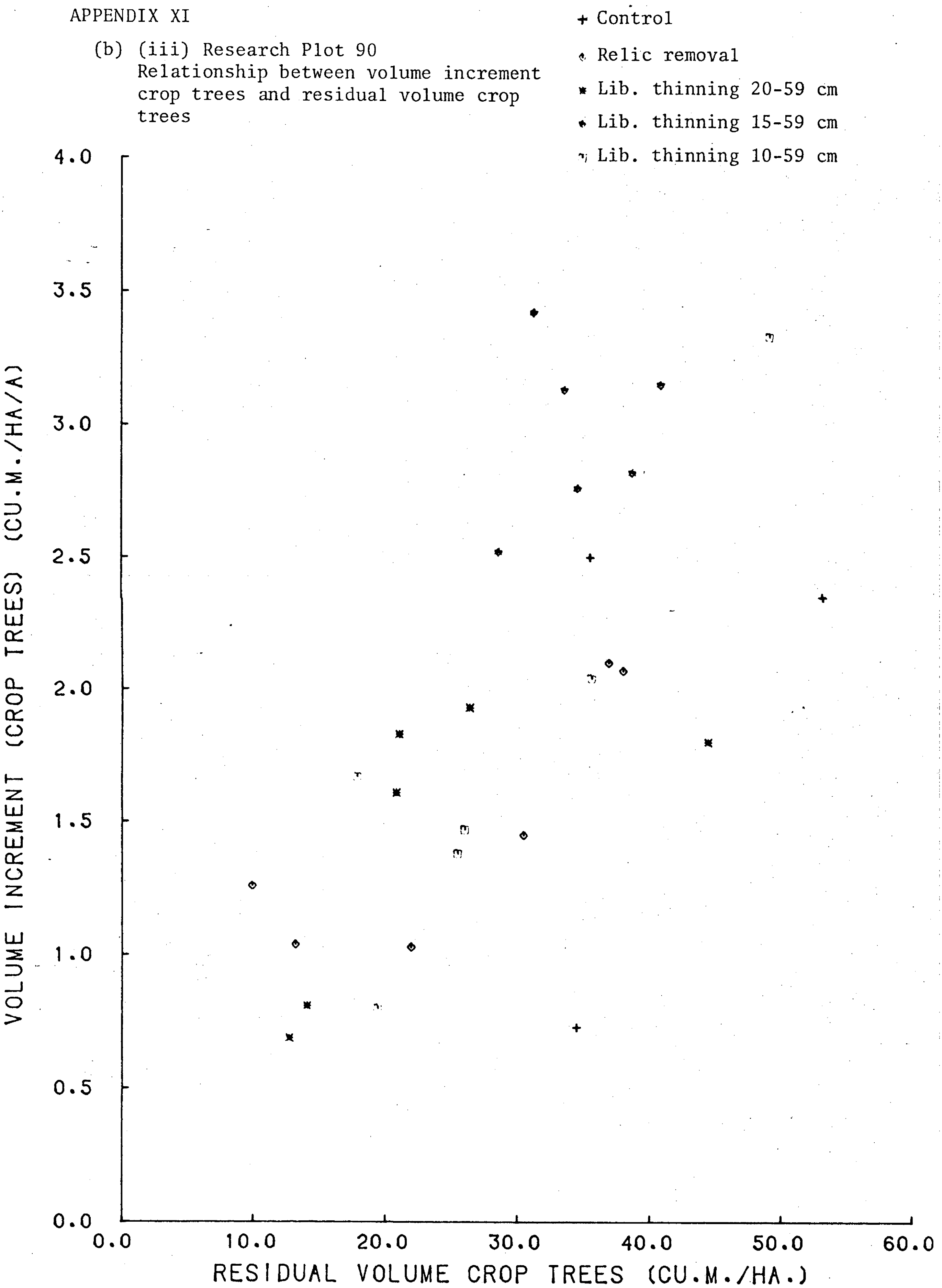
APPENDIX XI

(b) (ii) Research Plot 68B
Relationship between volume increment and residual volume crop trees



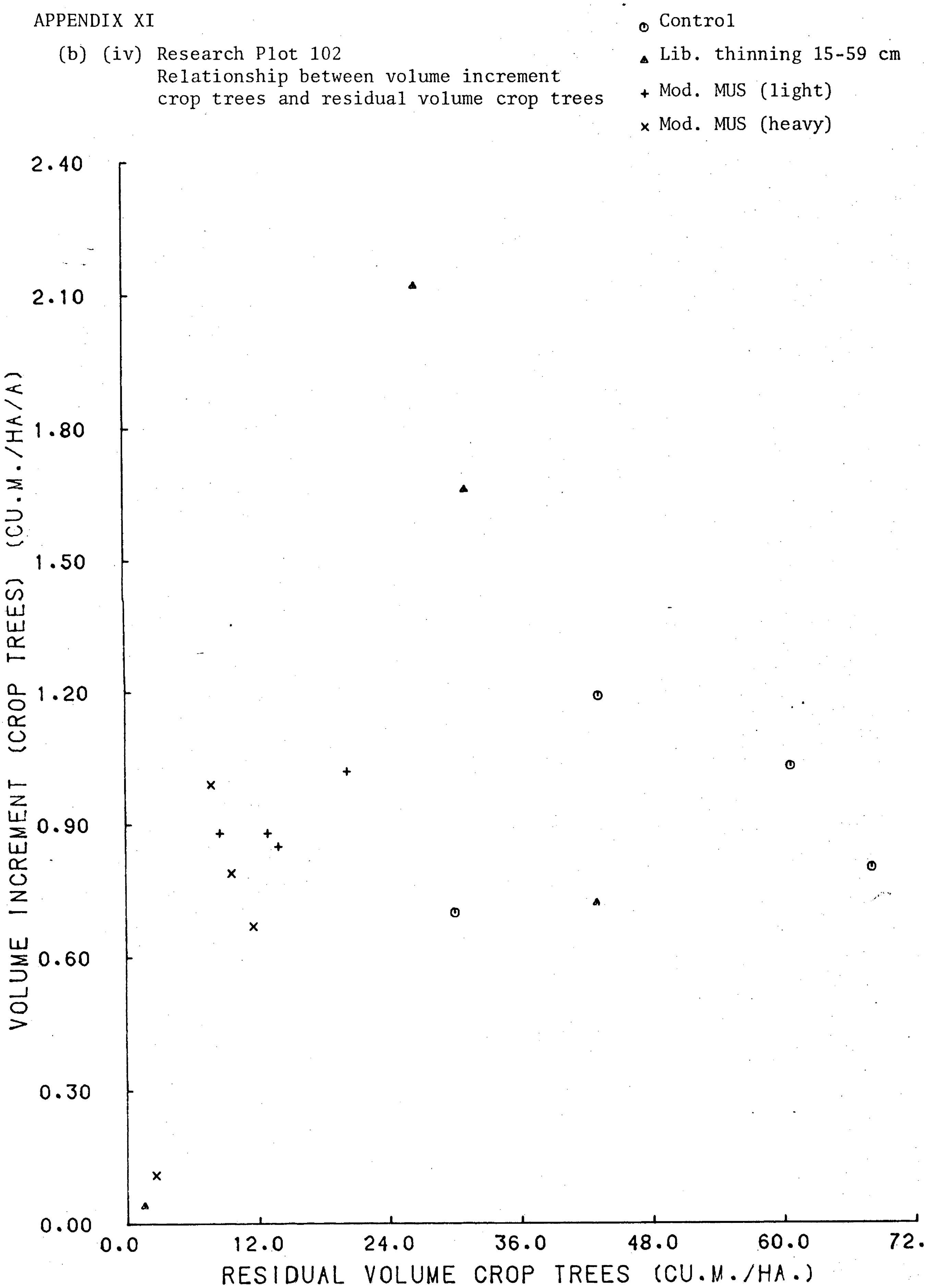
APPENDIX XI

(b) (iii) Research Plot 90
Relationship between volume increment crop trees and residual volume crop trees



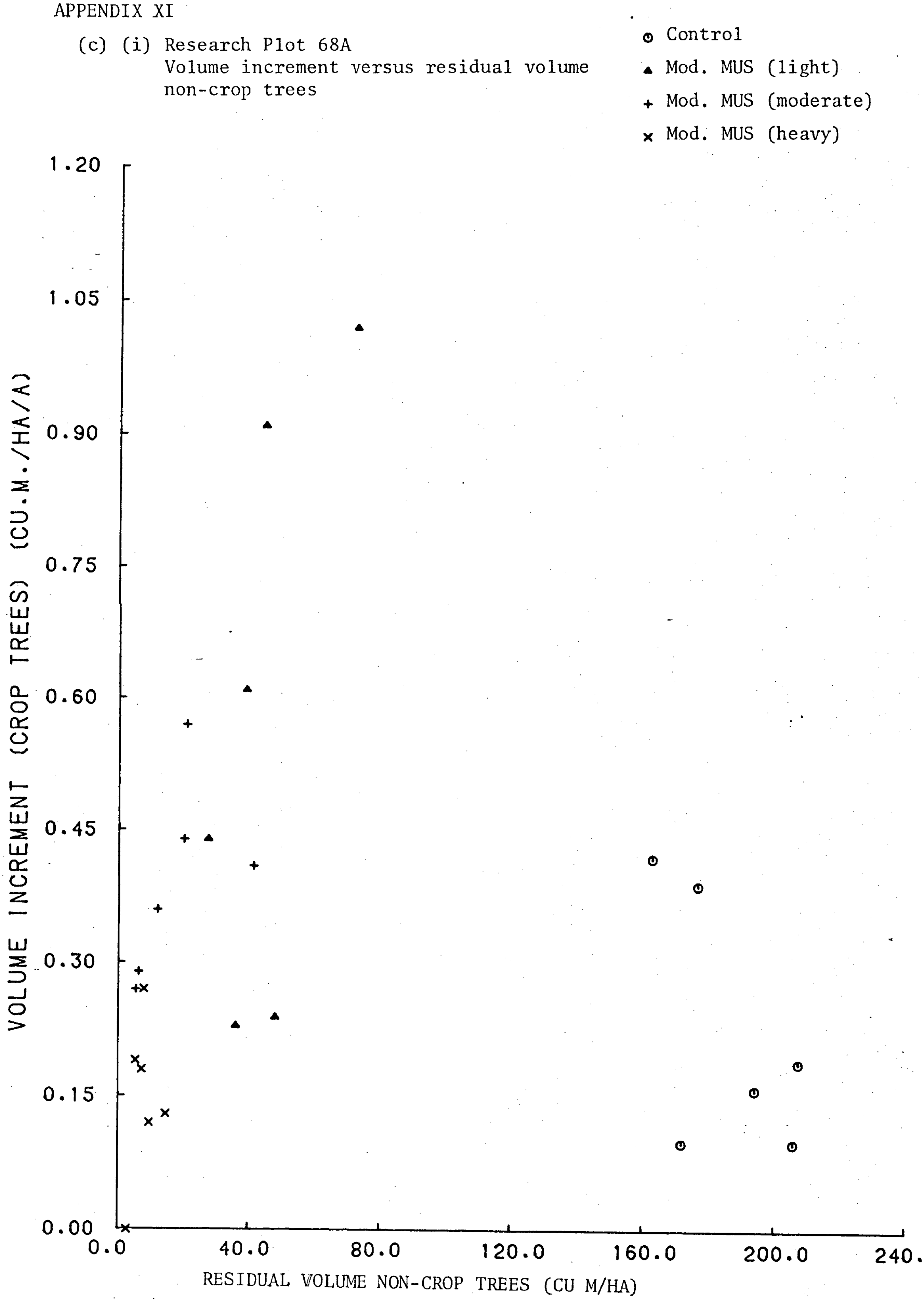
APPENDIX XI

(b) (iv) Research Plot 102
Relationship between volume increment crop trees and residual volume crop trees



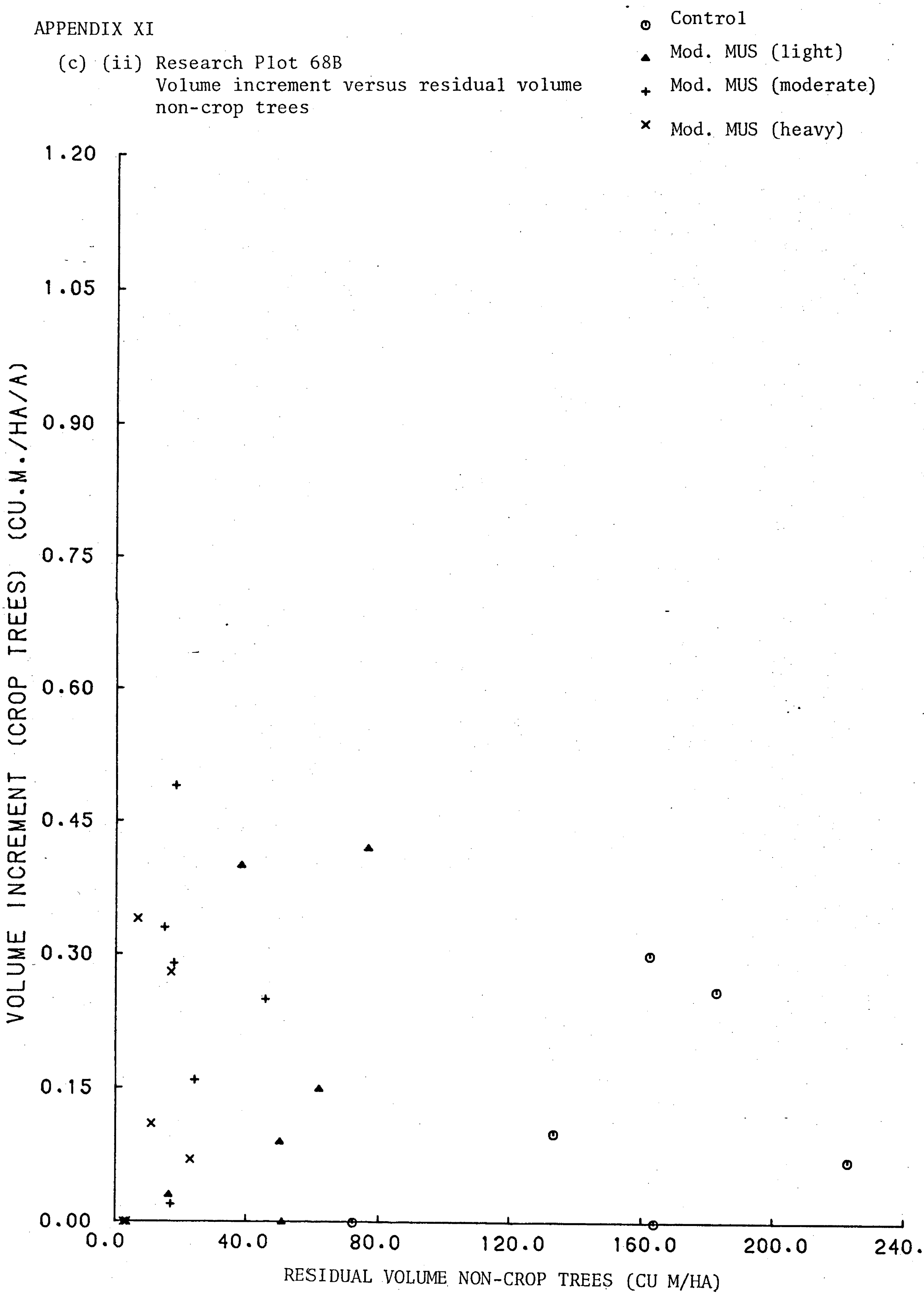
APPENDIX XI

(c) (i) Research Plot 68A
Volume increment versus residual volume non-crop trees



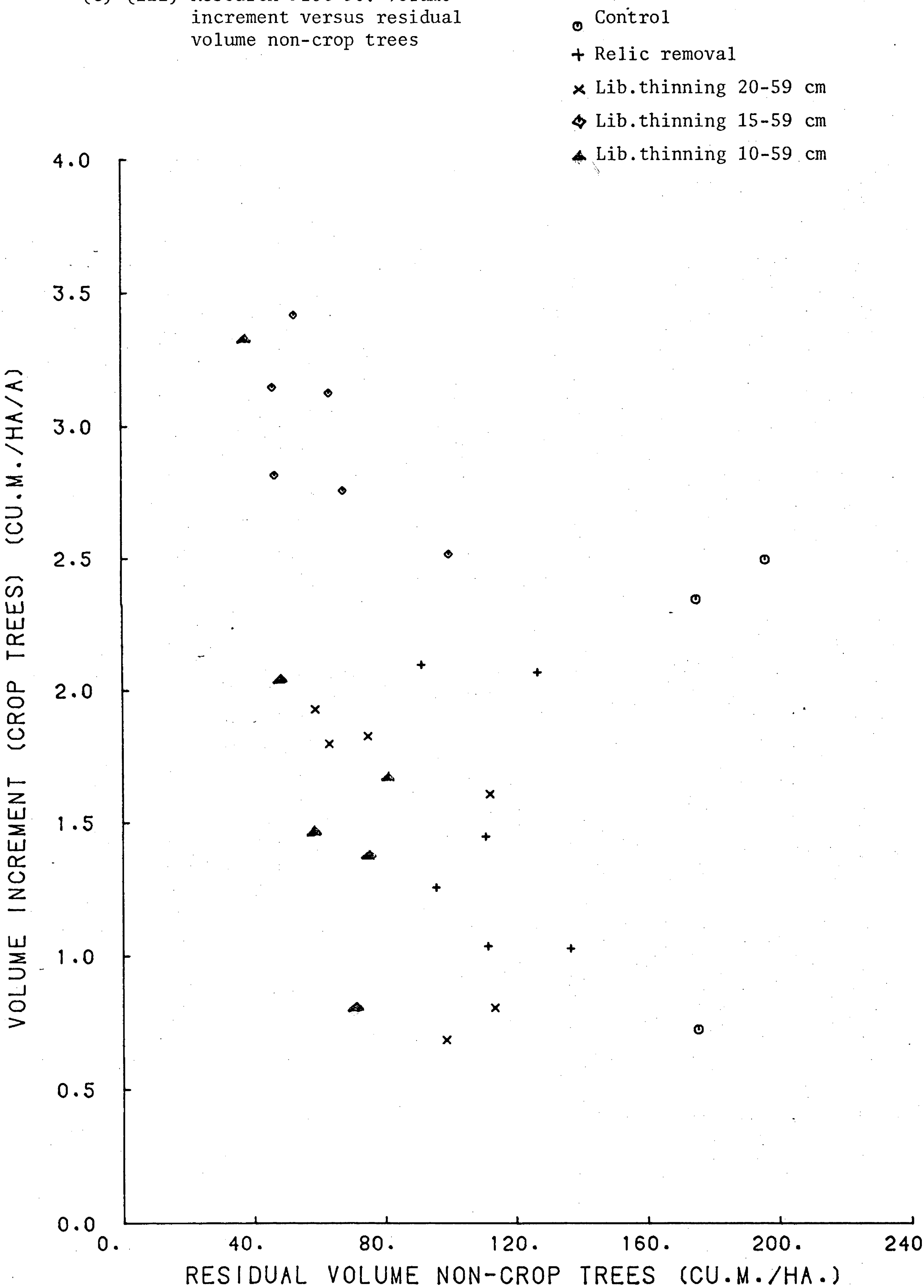
APPENDIX XI

(c) (ii) Research Plot 68B
Volume increment versus residual volume non-crop trees



APPENDIX XI

(c) (iii) Research Plot 90. Volume increment versus residual volume non-crop trees



APPENDIX XI

(c) (iv) Research Plot 102
Volume increment versus residual volume non-crop trees